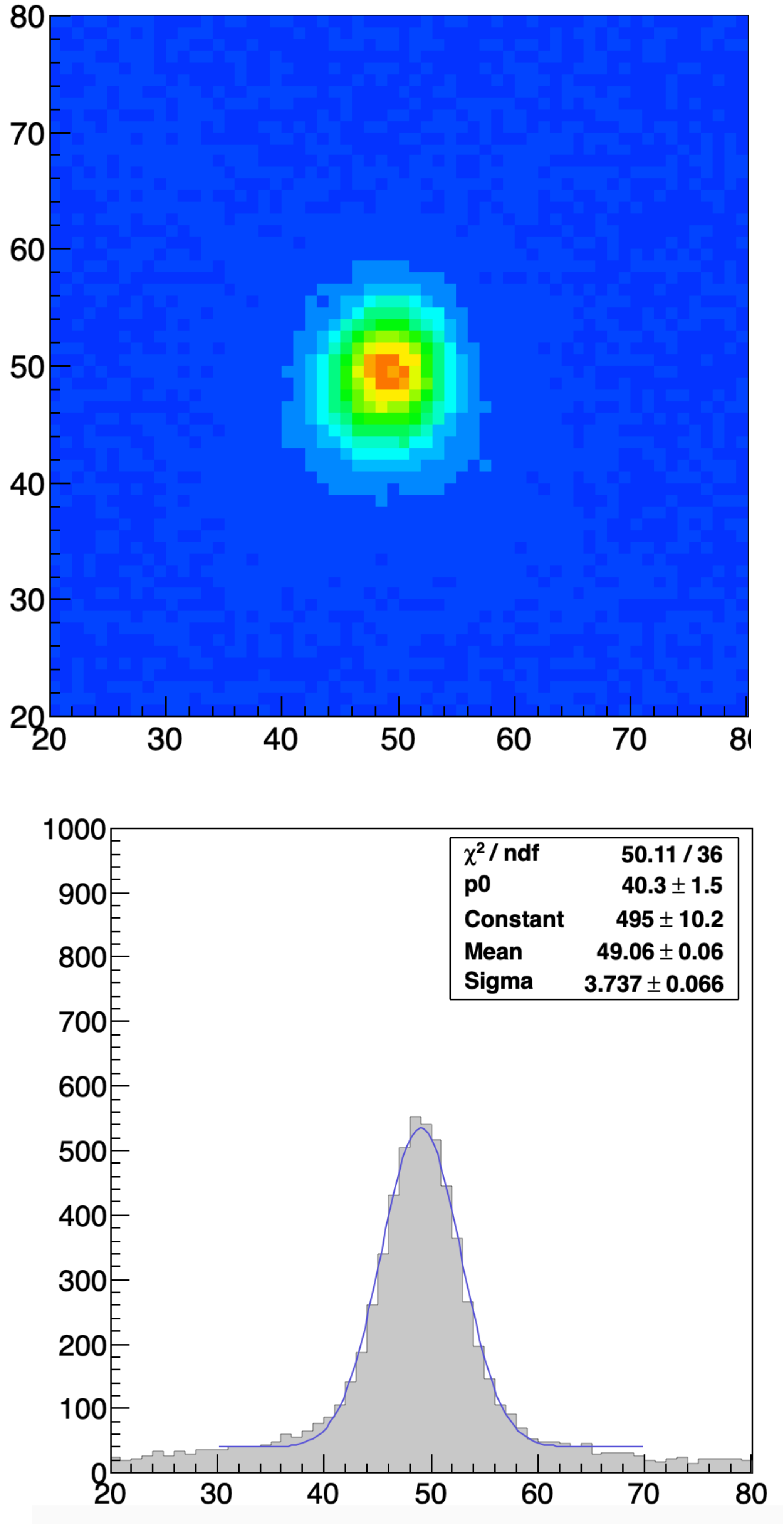
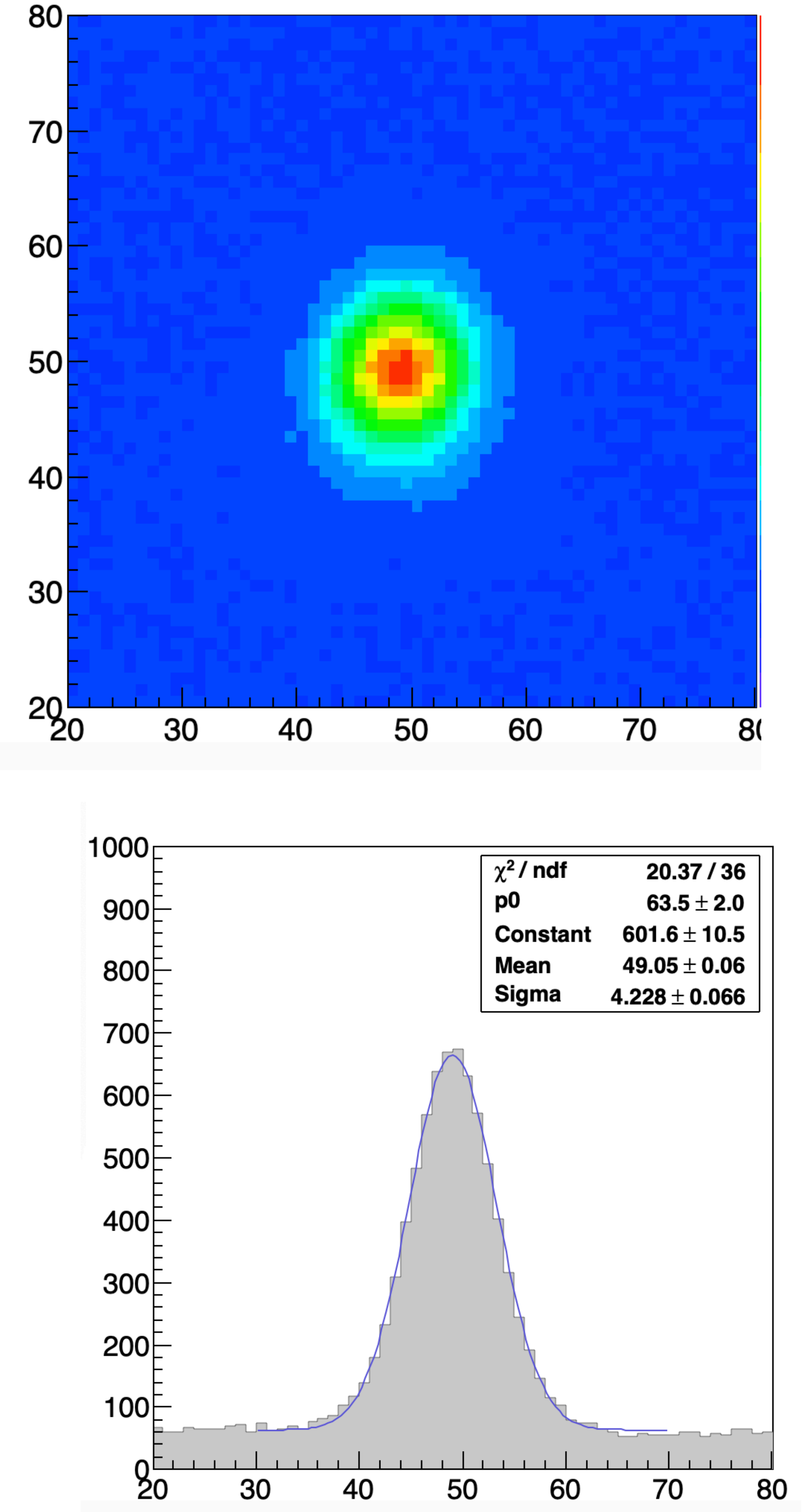
Study of ^{55}Fe spot in LIME
(aka Saturation and other effects)

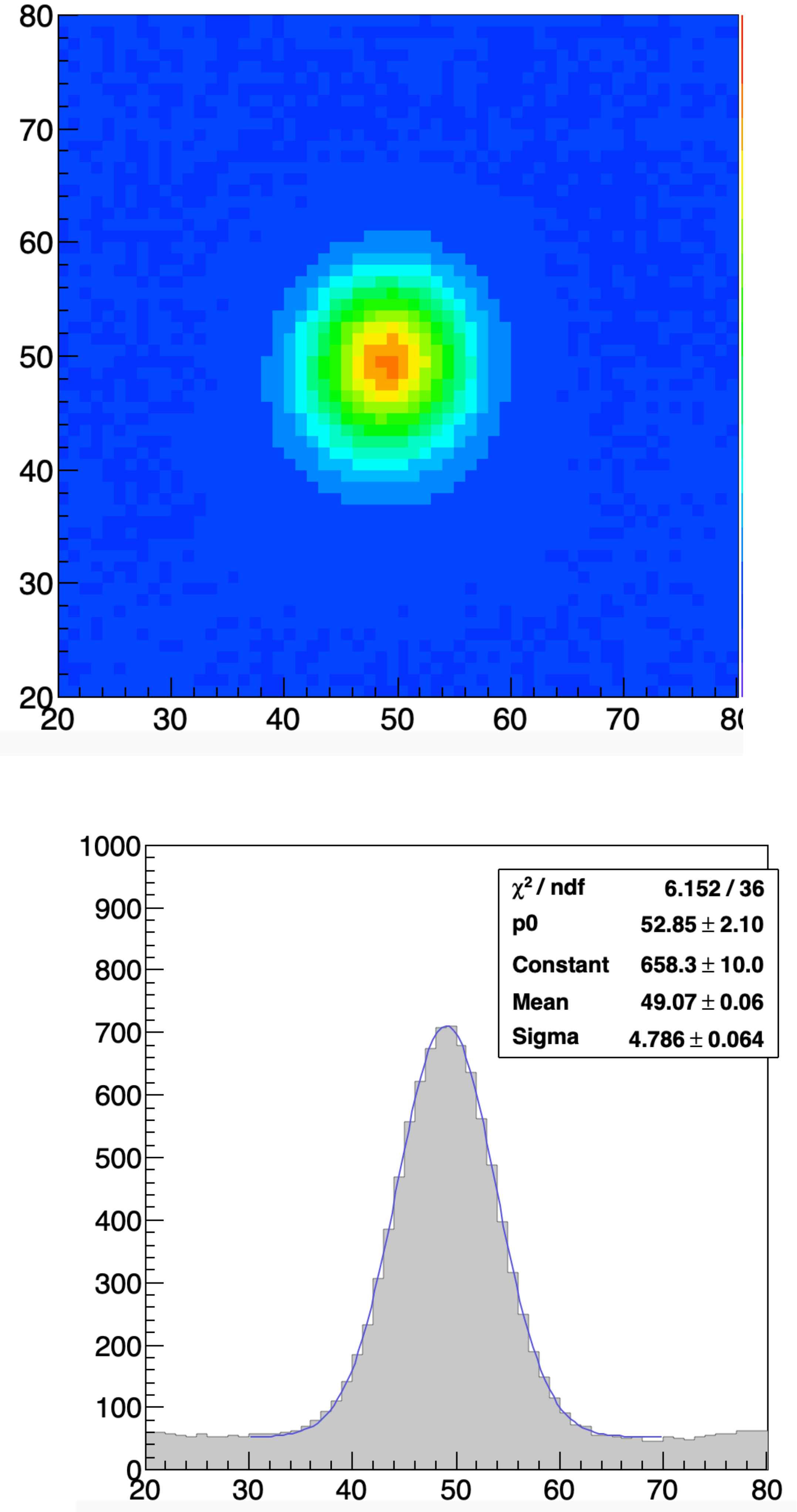
Experimental spot shapes



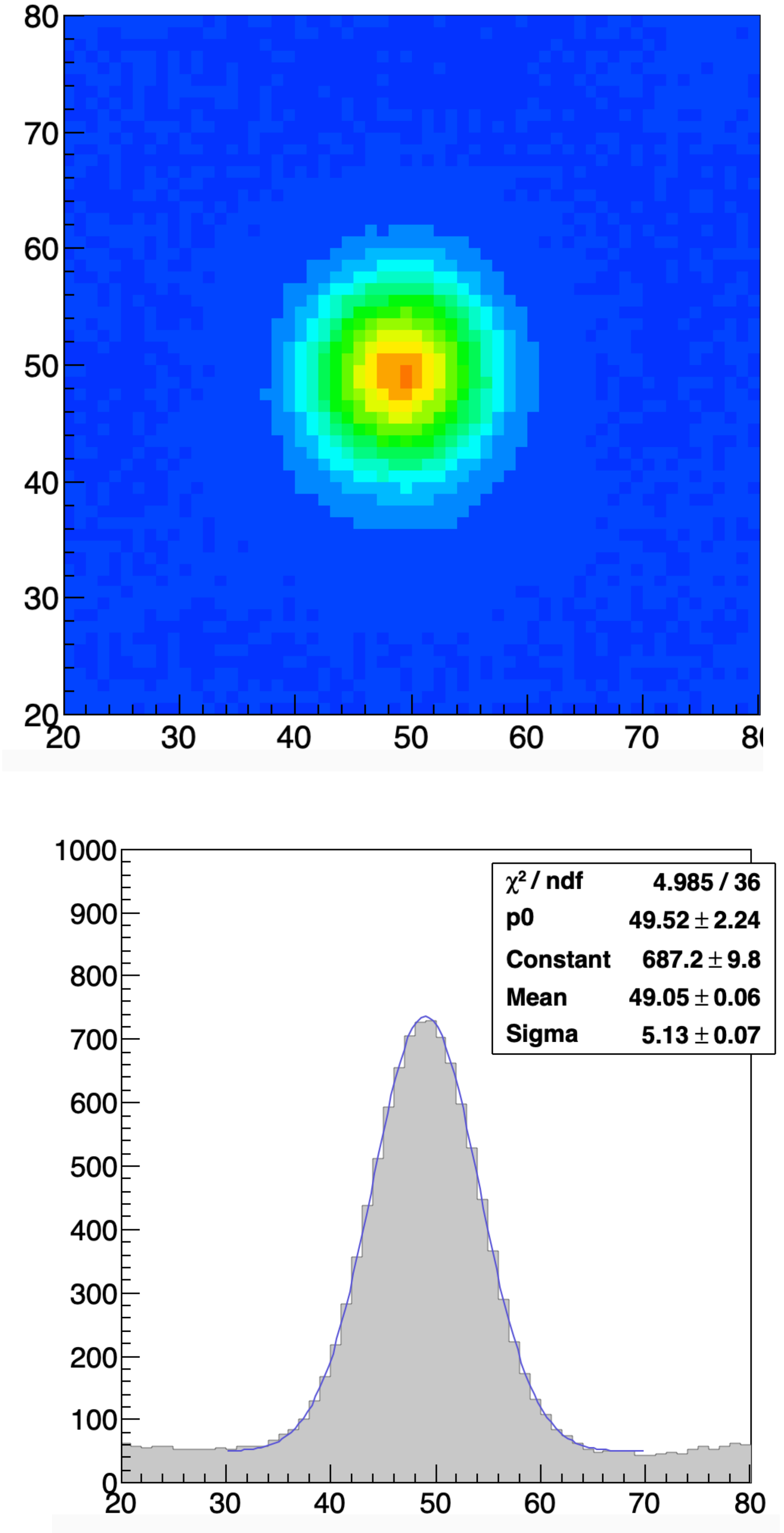
6 cm - light = 4635



11 cm - light = 6373



16 cm - light = 7895

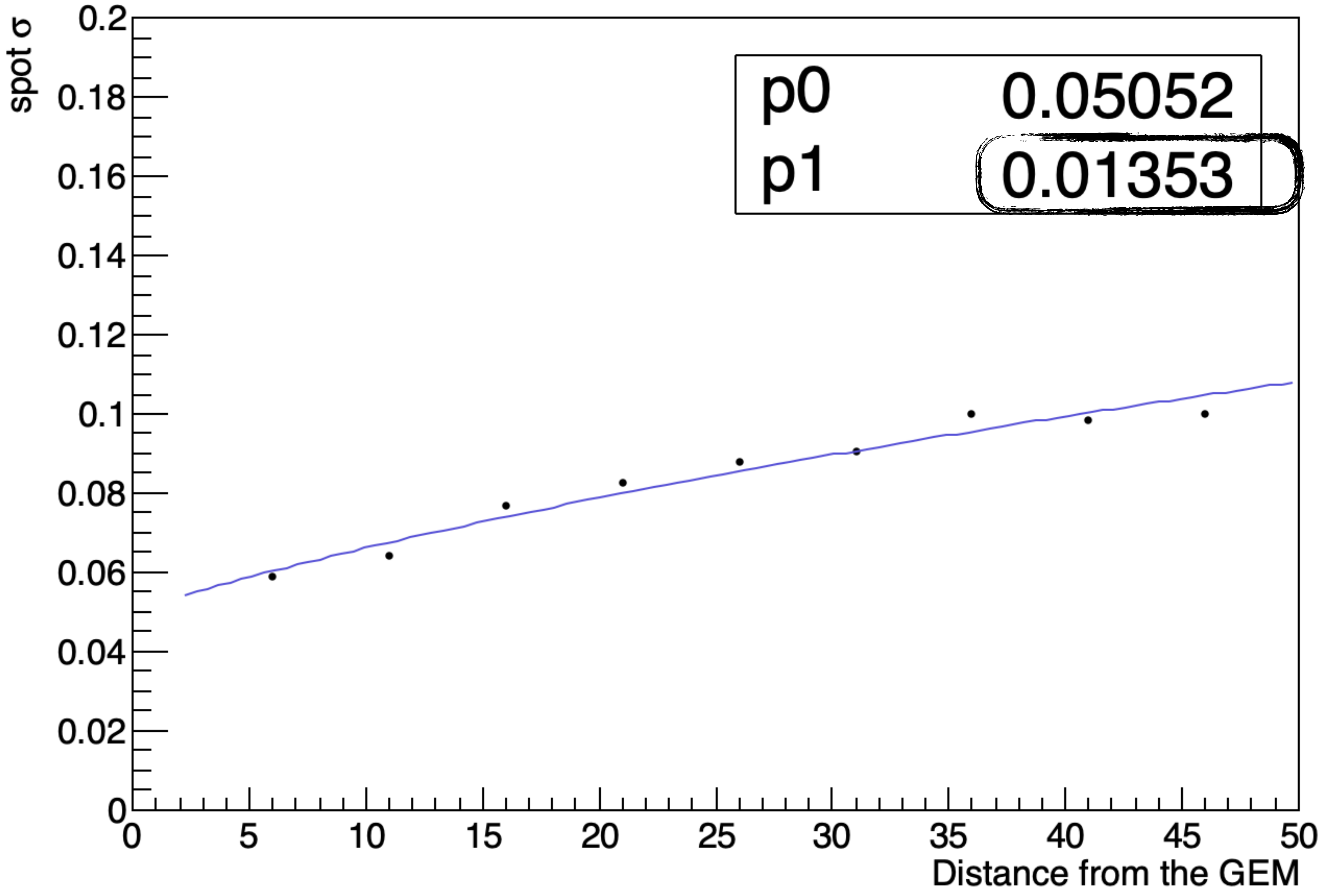


21 cm - light = 8834

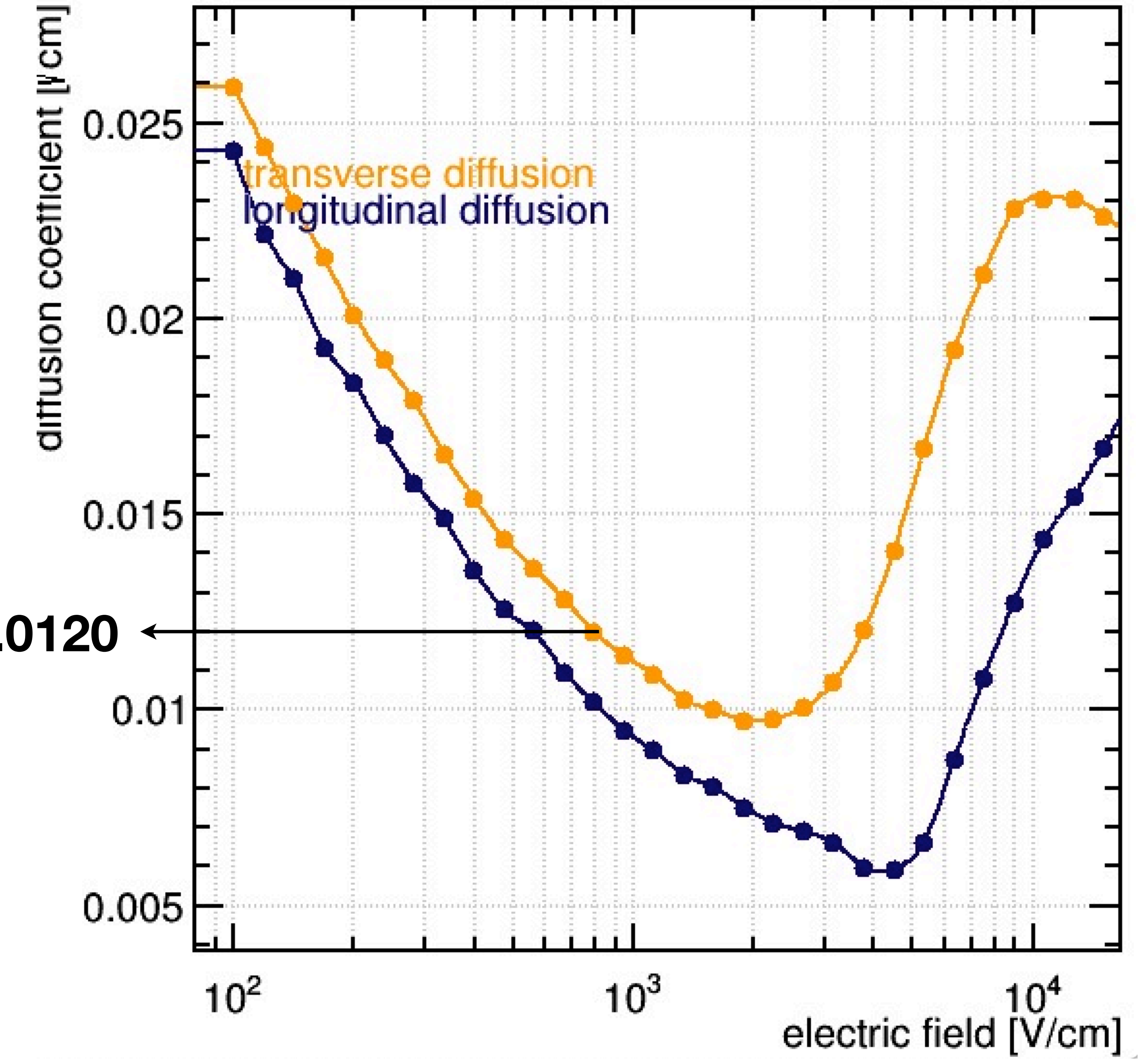
Experimental spot shapes

26 cm - 9659 **31 cm - 10001** **36 cm - 10379** **41 cm - 10436** **46 cm - 10480**

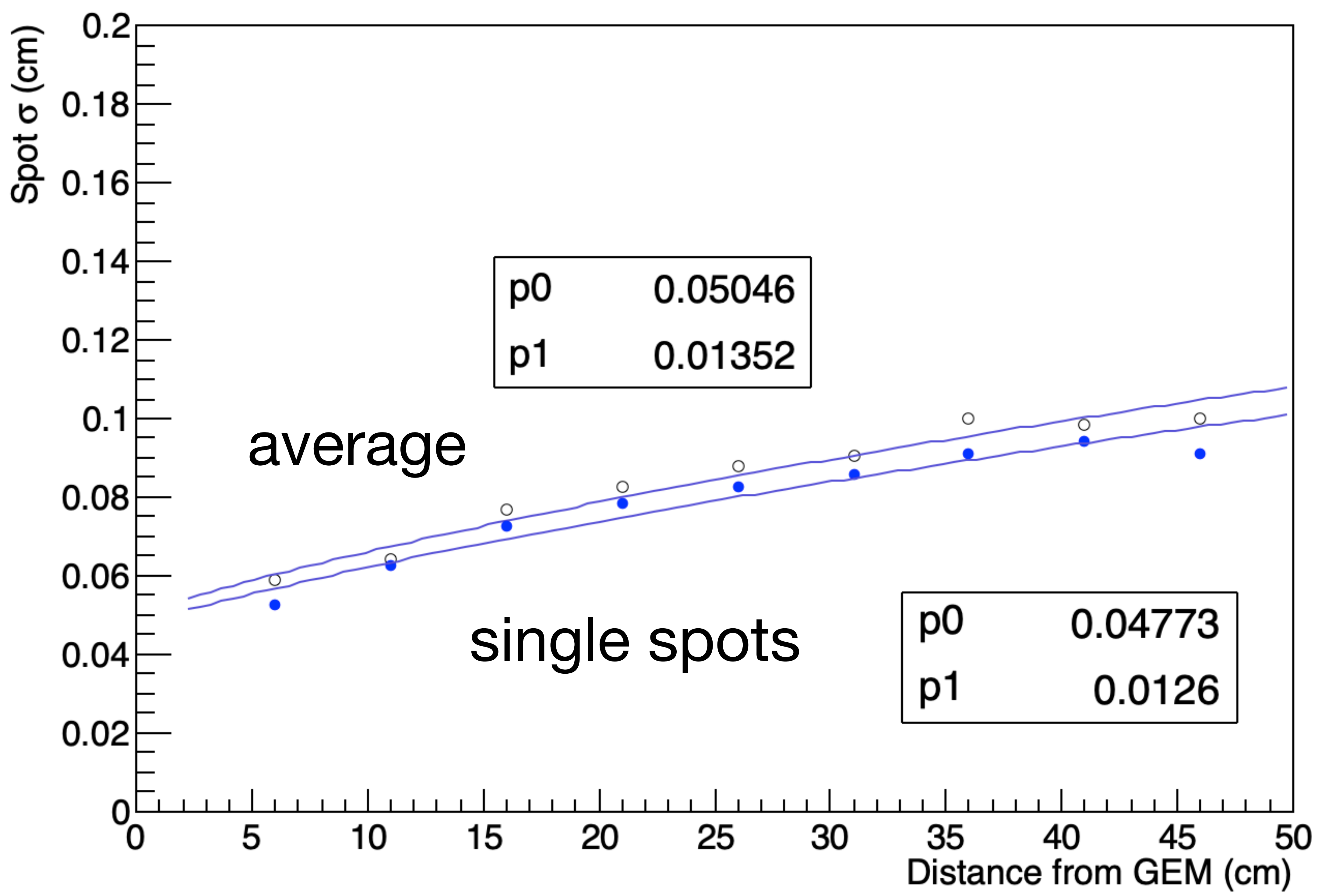
Experimental spot shapes

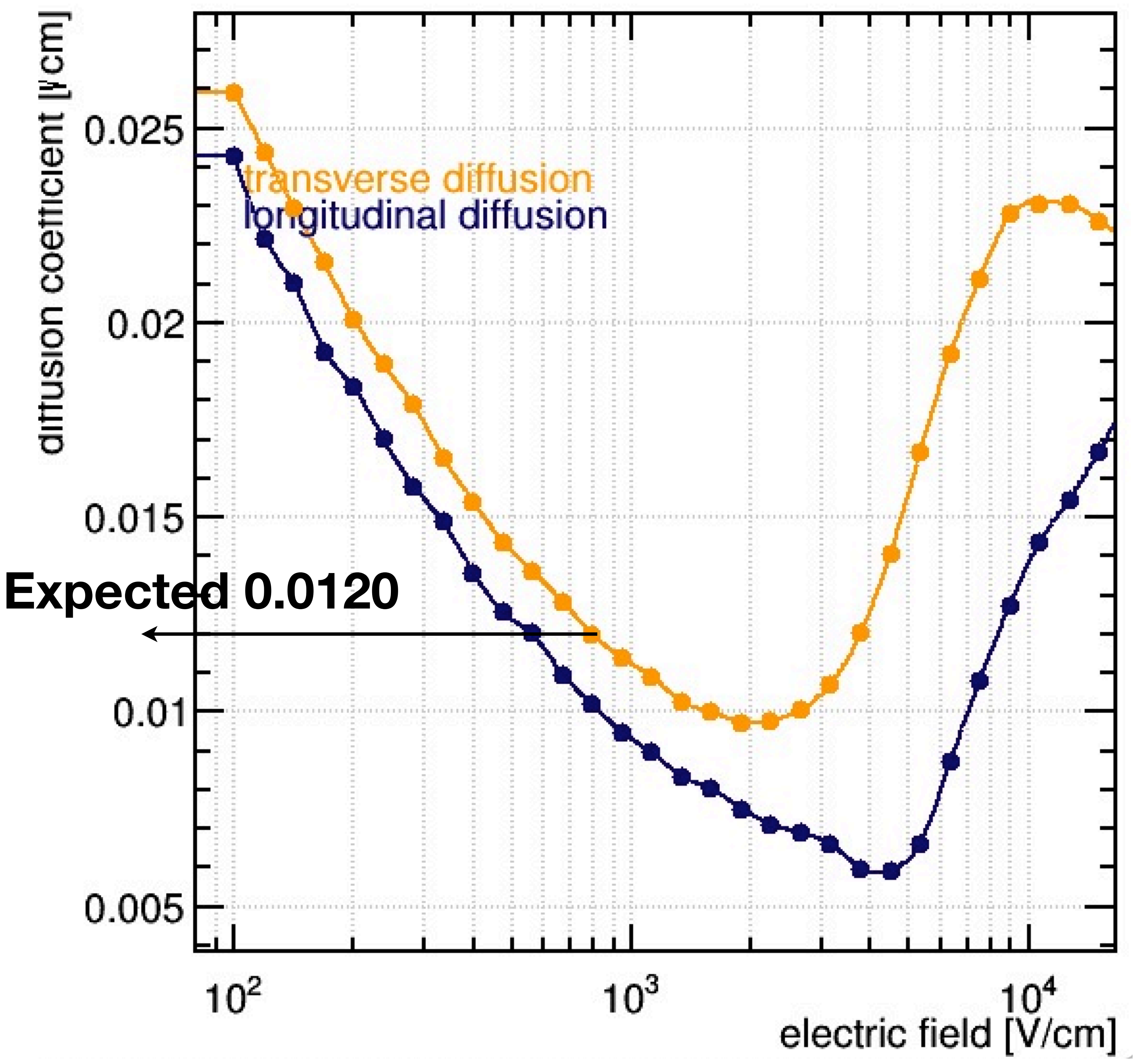


Expected 0.0120



Experimental spot shapes





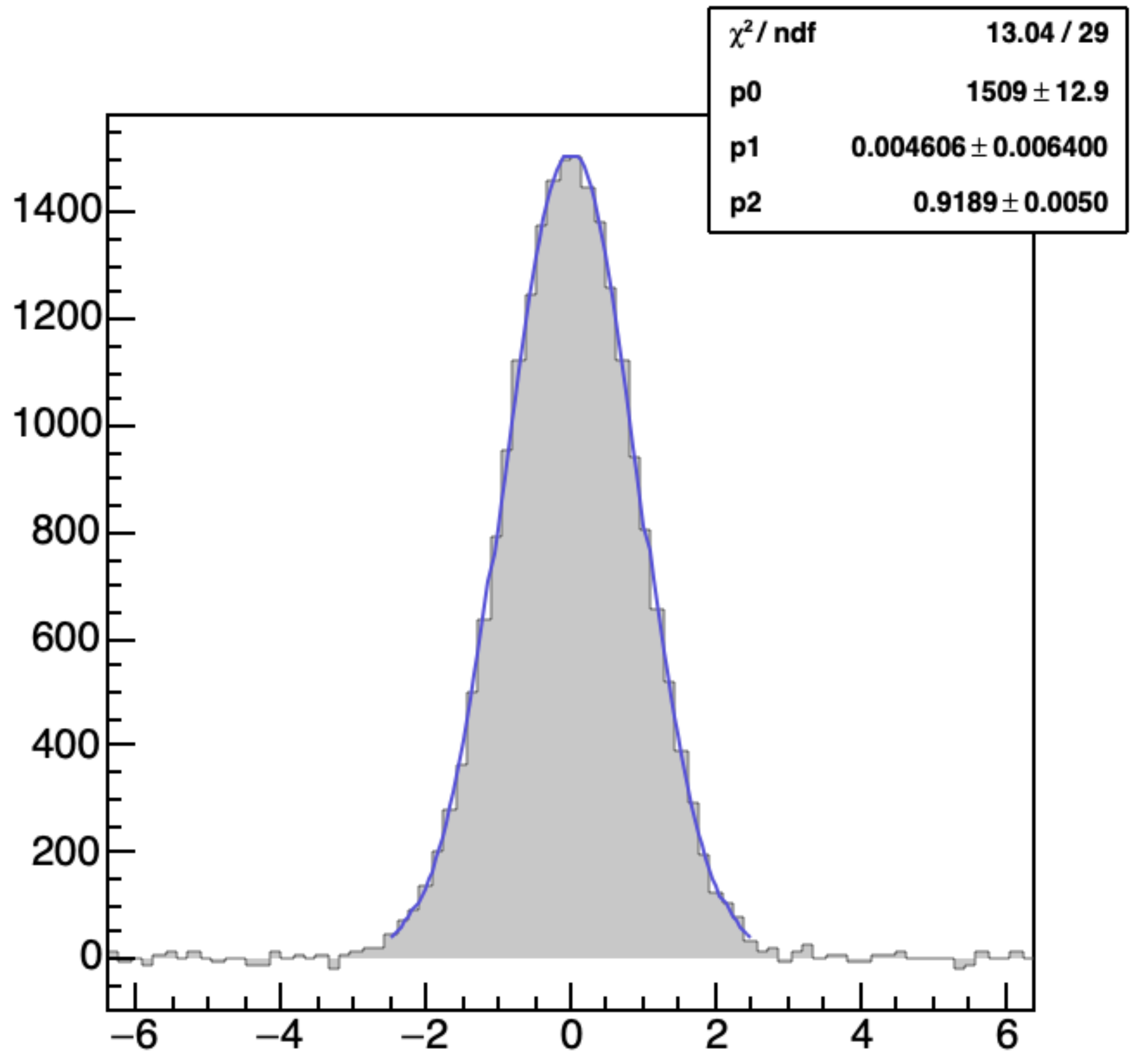
Performed the same analysis spot-by-spot instead of the average one

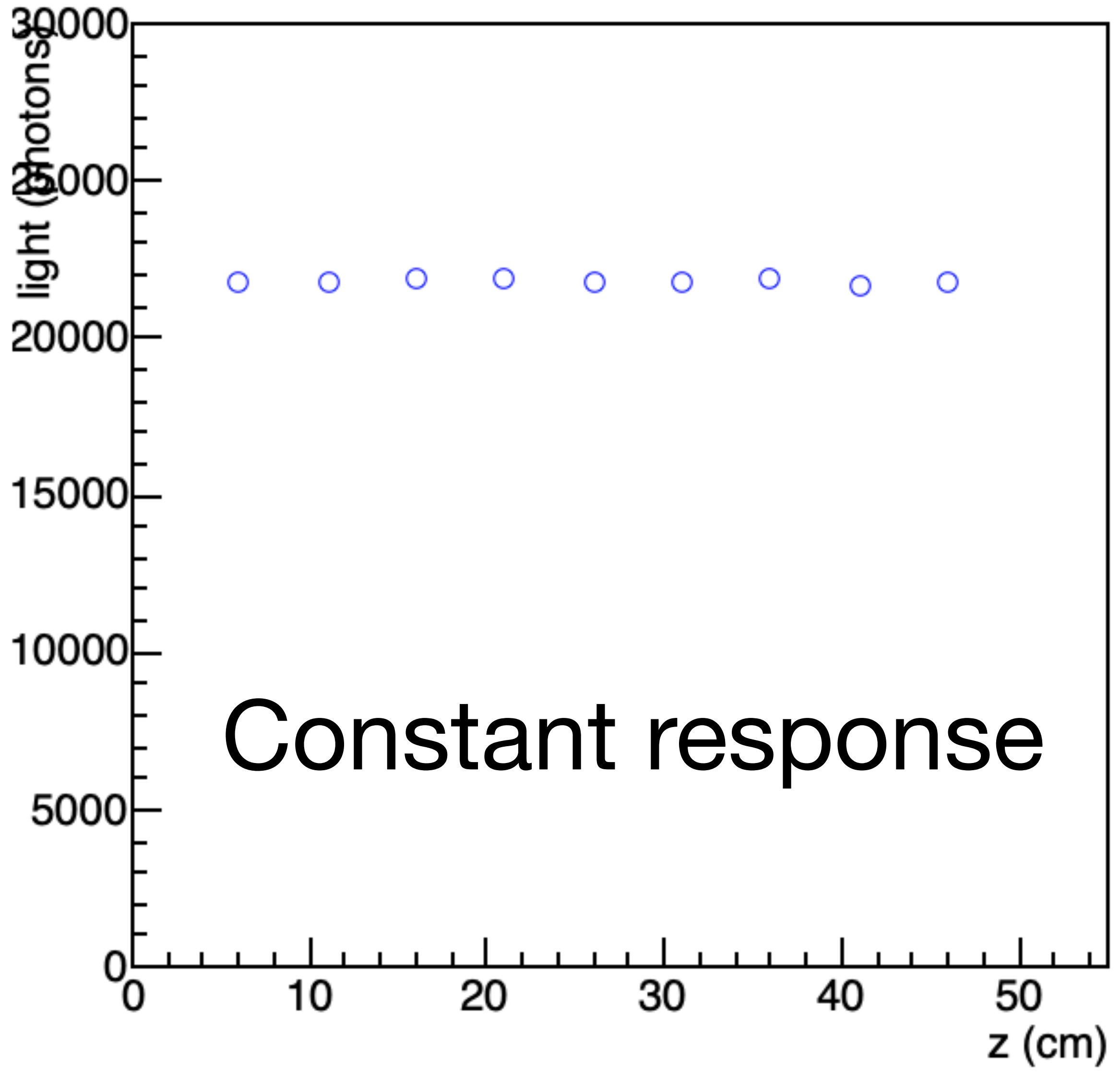
Behavior is very similar

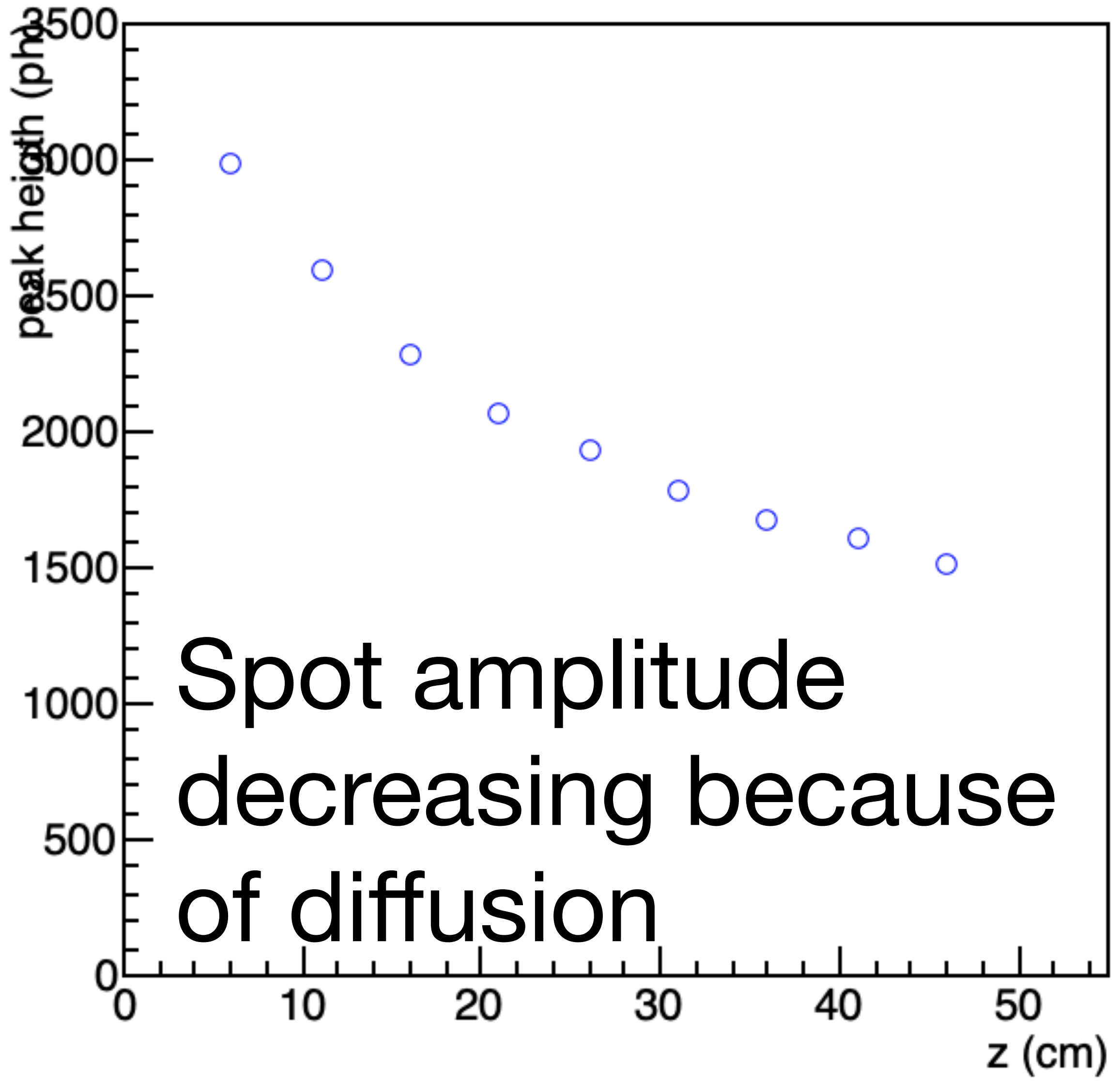
Ideal behaviour

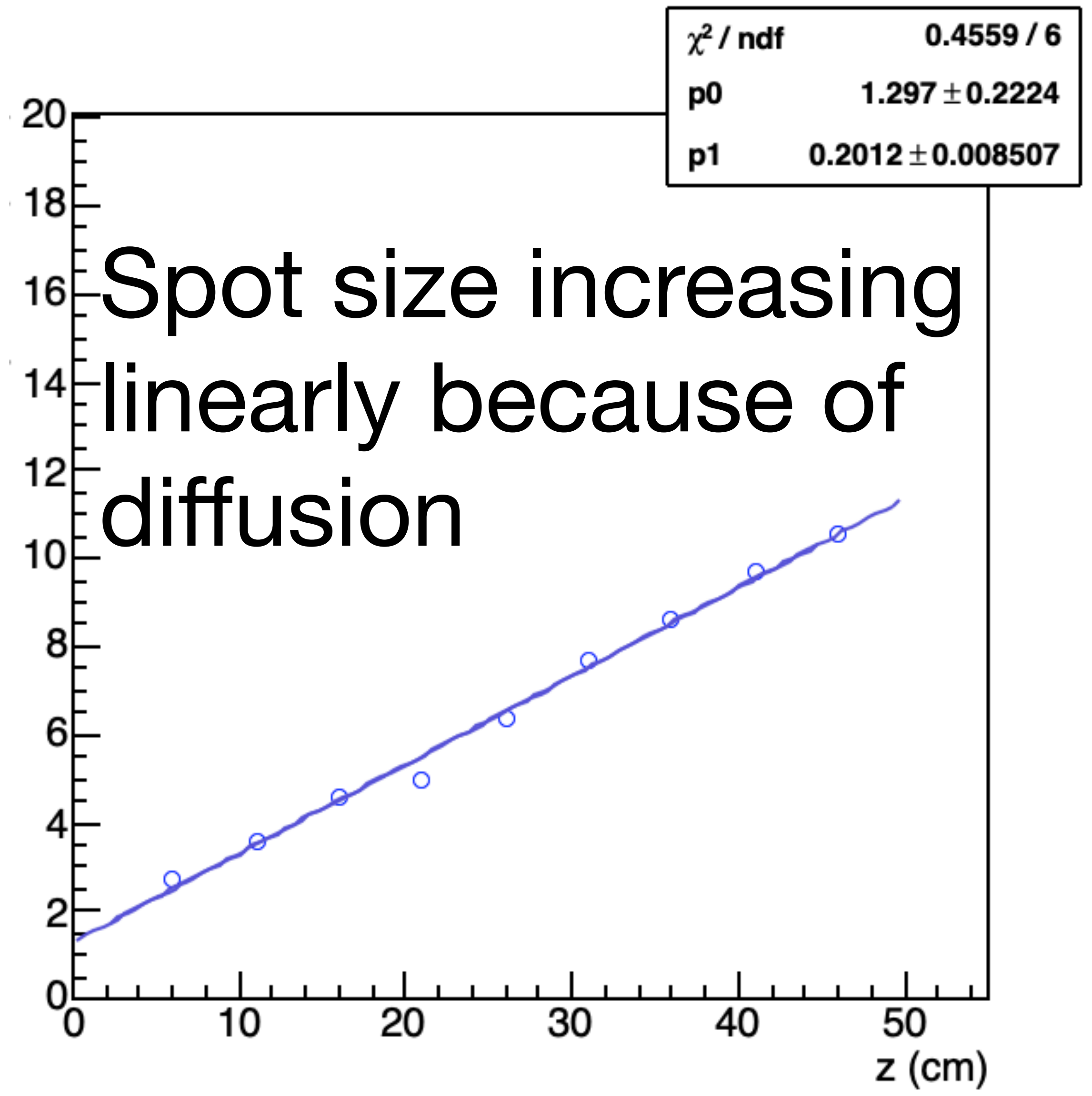
In an ideal optical TPC:

- charges are efficiently drifted toward GEM;
- gain and light yield (ph/e) are constant -> linearity between light production and ionization;
- null sensor noise;







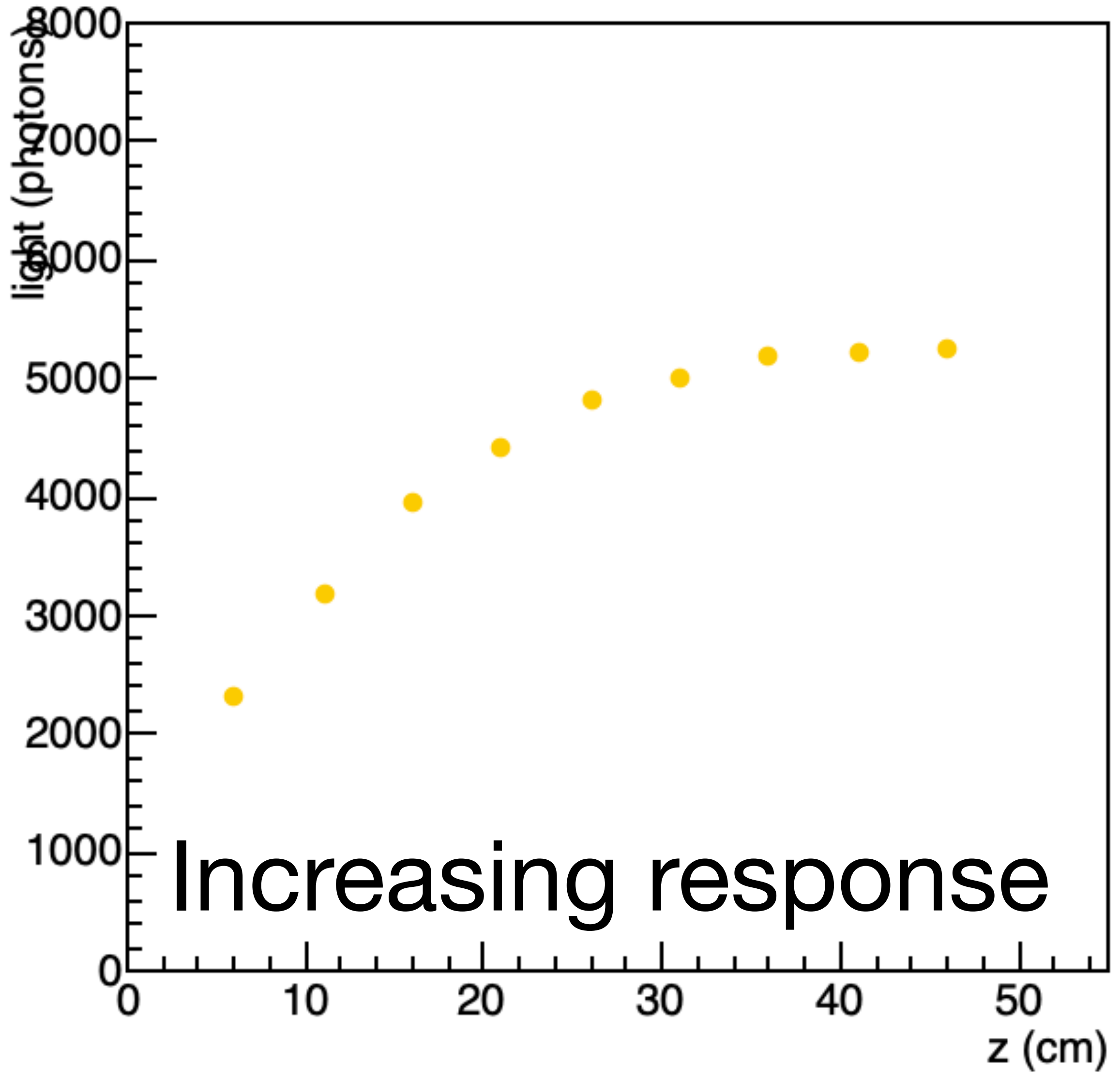


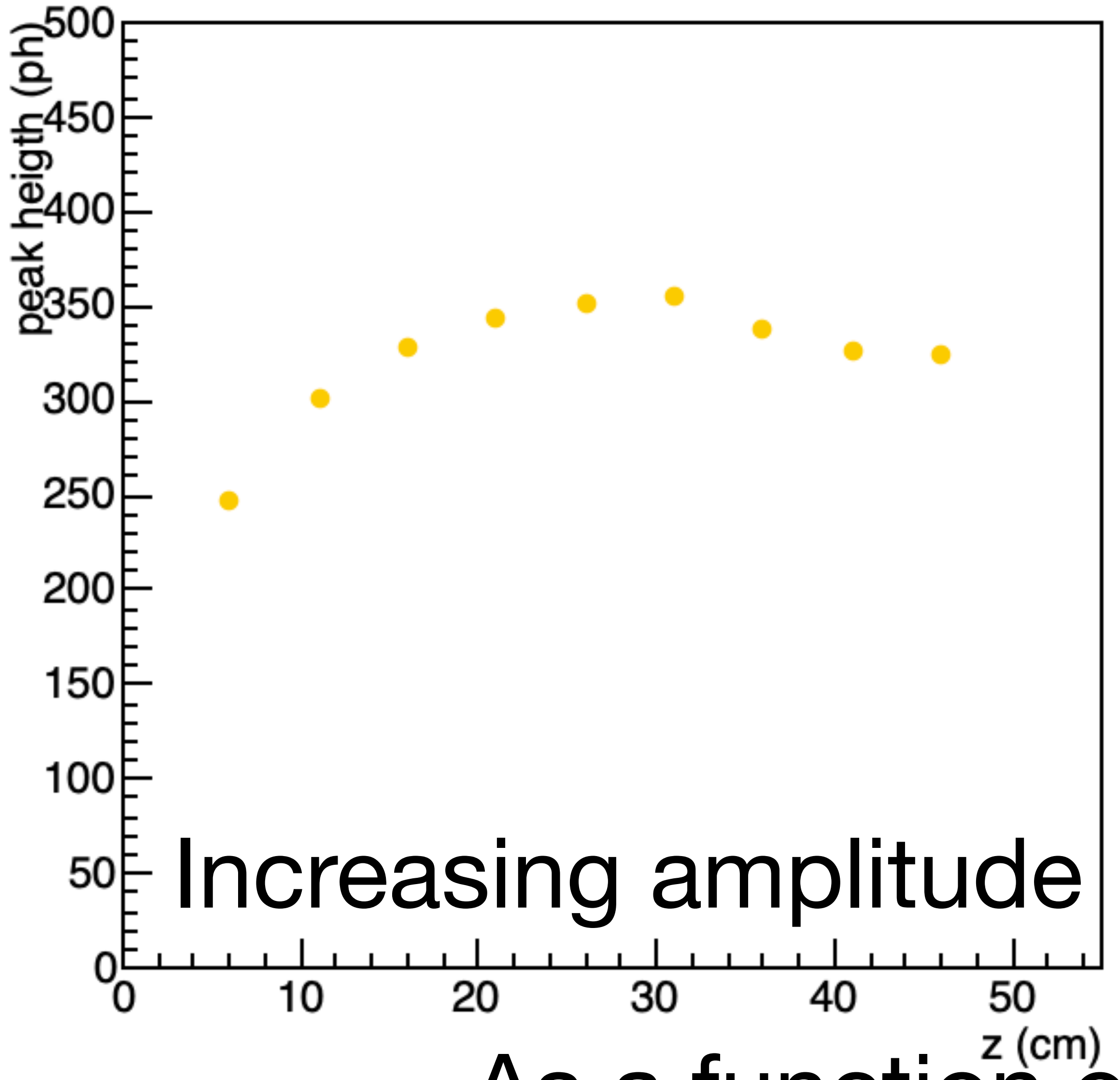
As a function of z (distance from GEM)

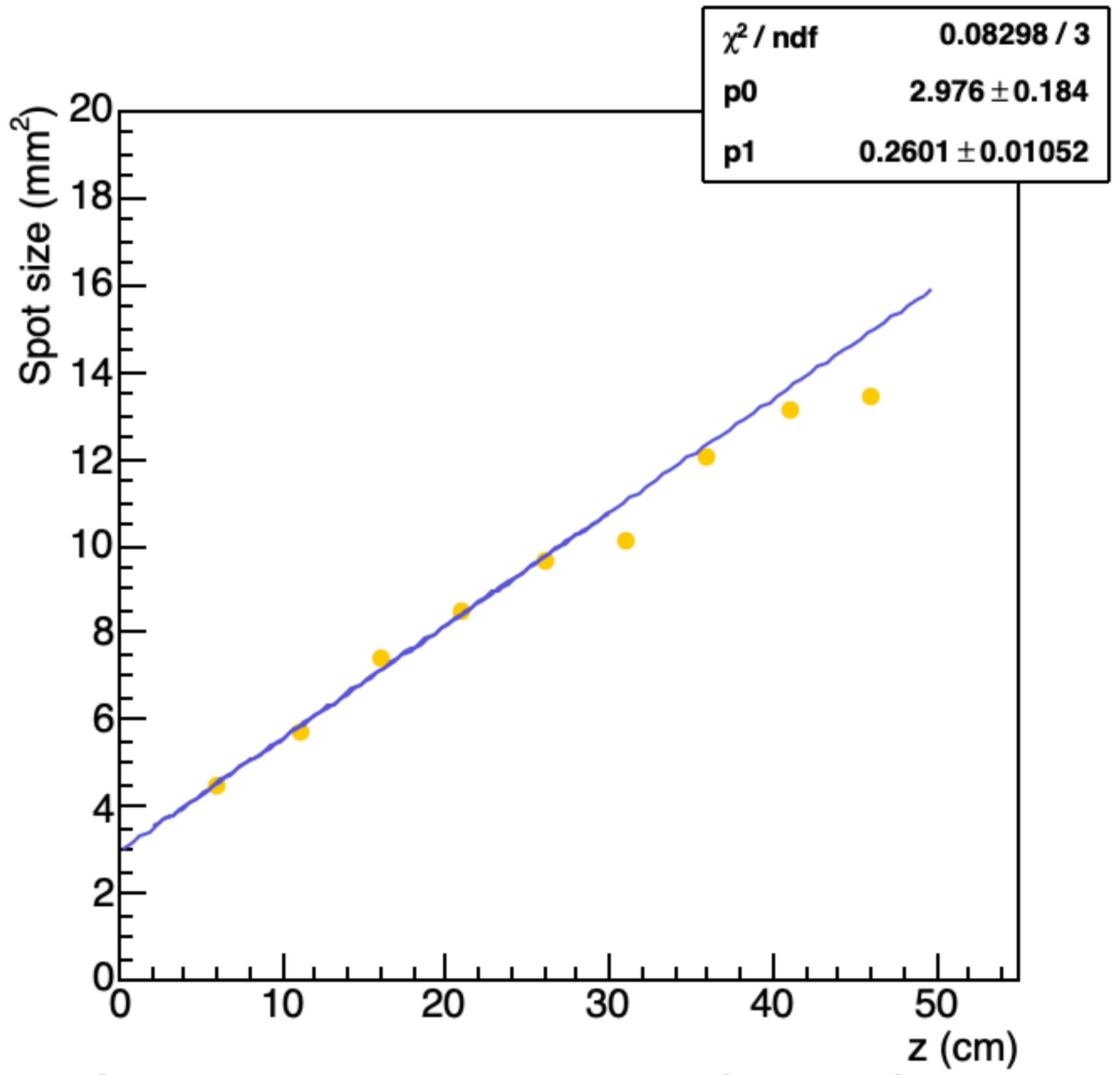
Real behaviour

In a real optical TPC:

- charges are inefficiently drifted toward GEM;
- gain and light yield (ph/e) are not constant -> no linearity between light production and ionization;
- no-null sensor noise;





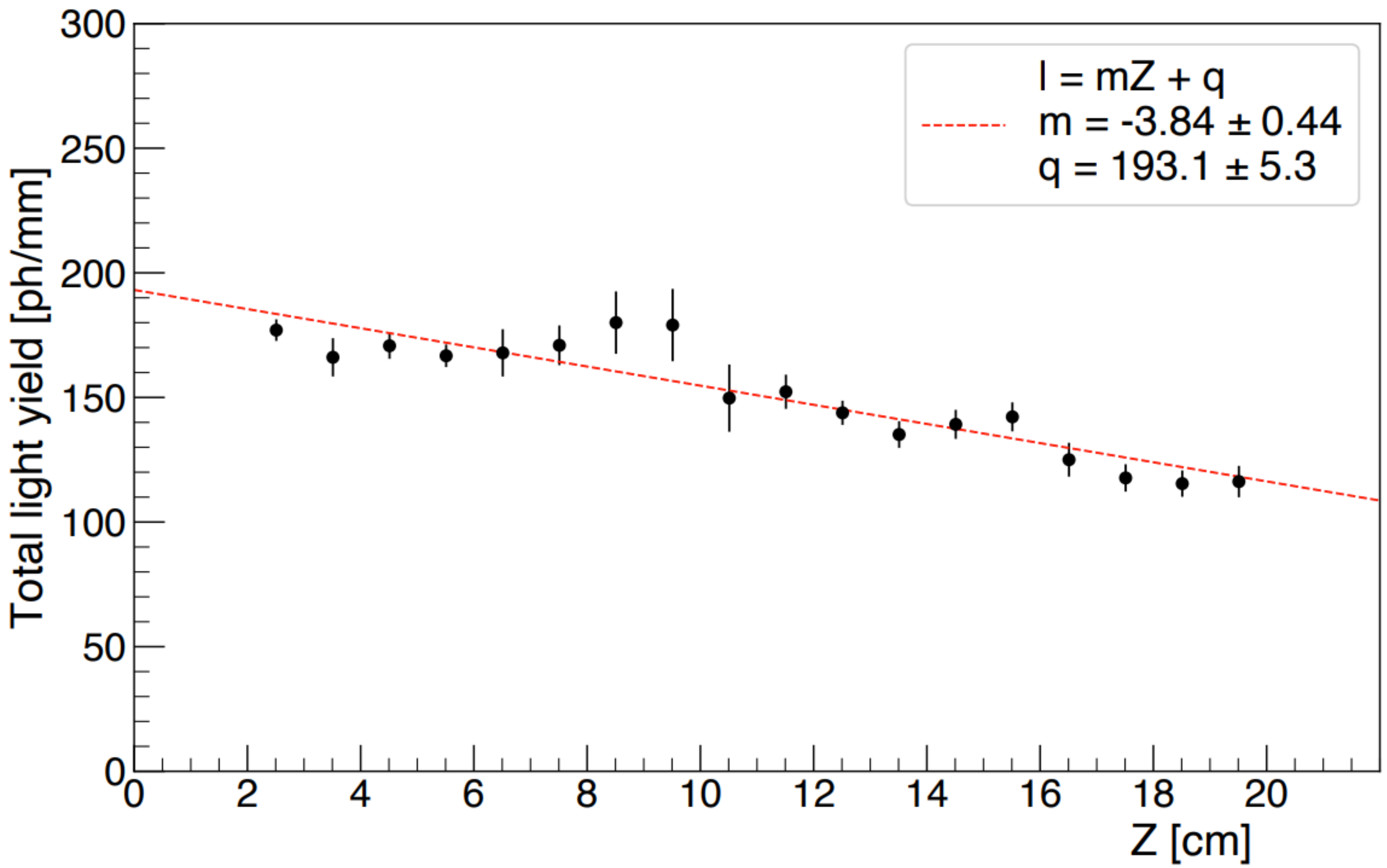


Spot size increasing because of diffusion with some loss at large Z values

As a function of z (distance from GEM)

Charge drift

An hint of some issue with charge transportation was found in BTF analysis:



Loss of 40% in 20 cm

$$n(z) = n_0 \, e^{-z/\lambda}$$

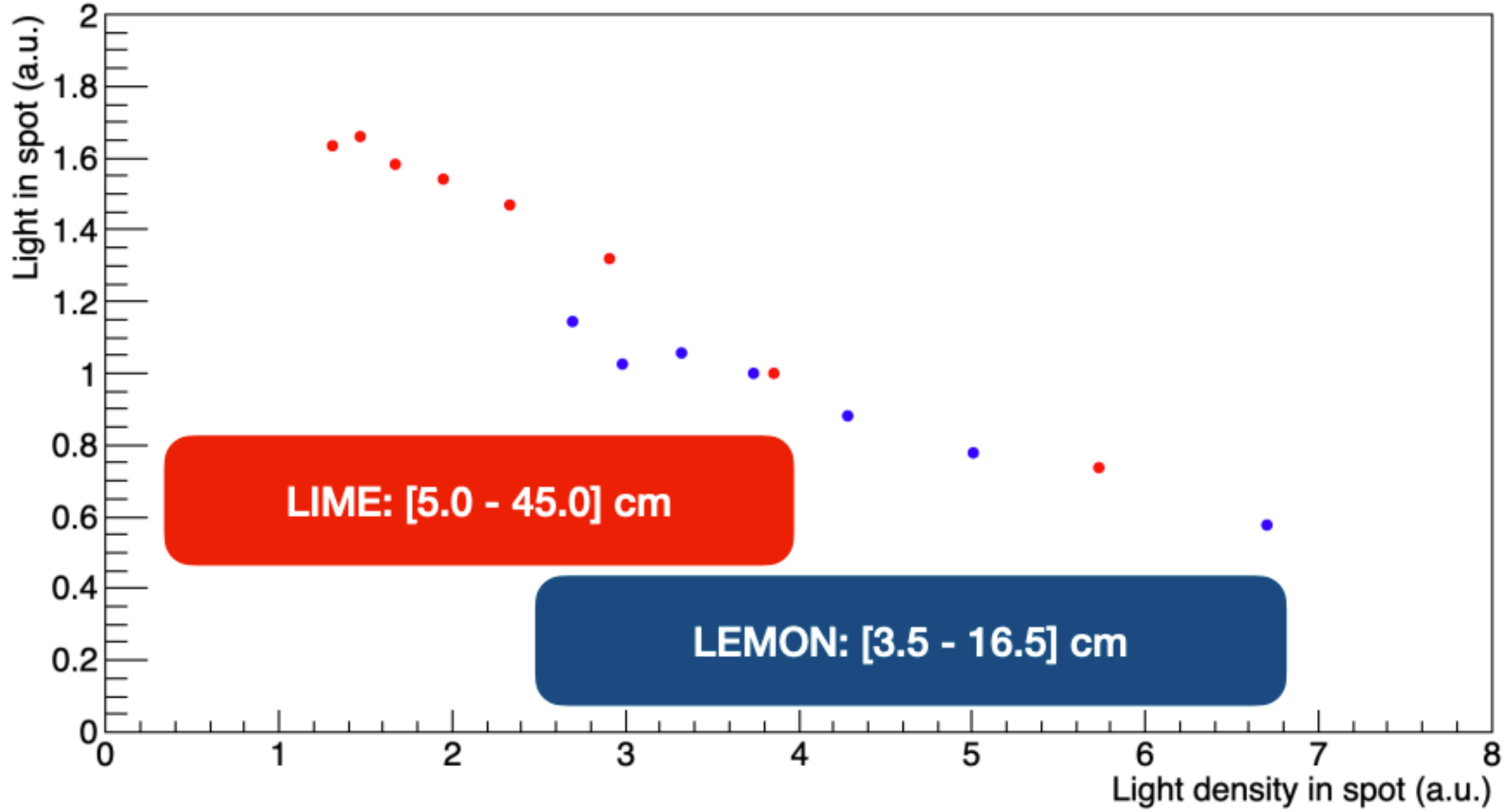
$$\lambda = 40 \text{ cm}$$

This is expected to be mainly due to impurities in gas;

LIME should be better than LEMON

Gain “saturation”

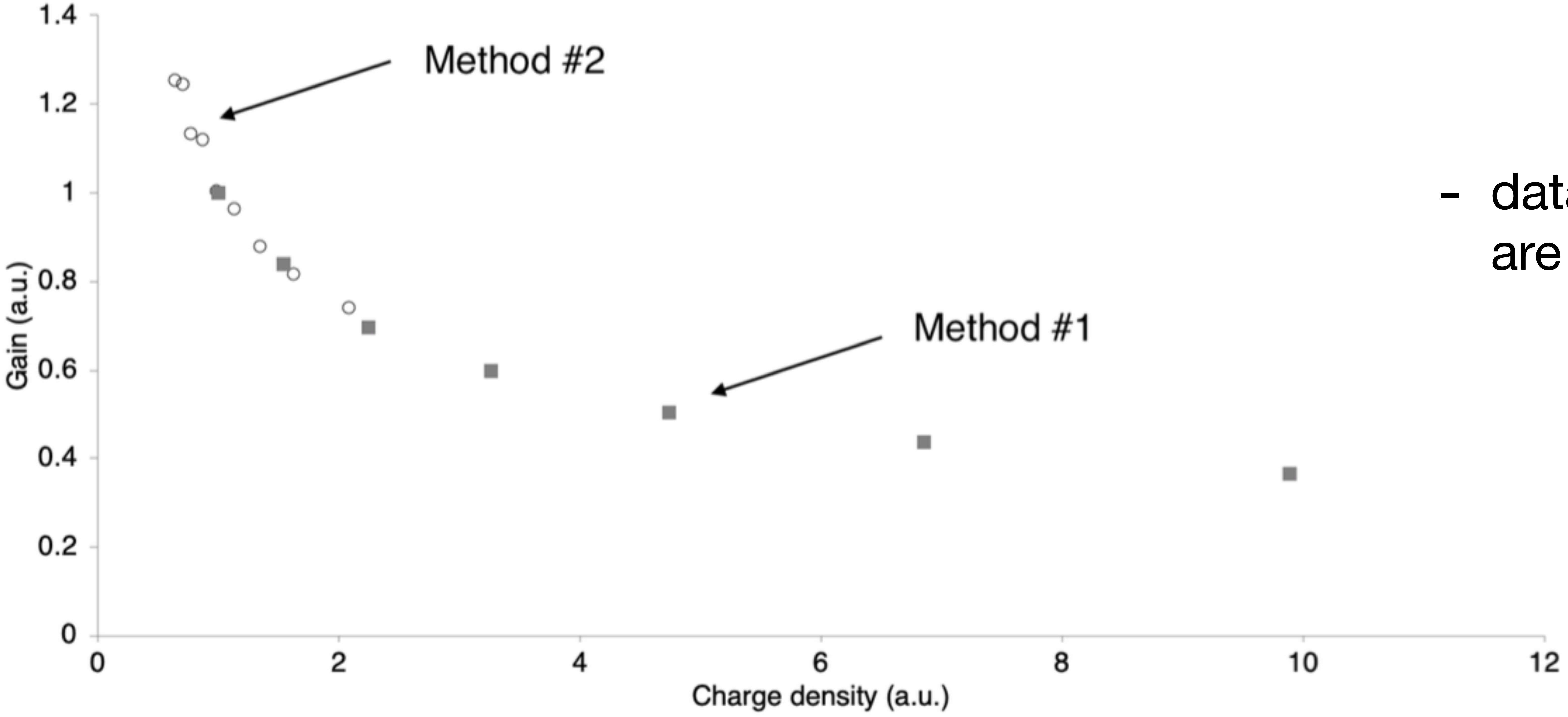
The average light collected in the ^{55}Fe spots is plotted as a function of the expected density evaluated from diffusion parameters simulated and confirmed by measurements



Comparison with current vs. distance measurements

Charge density on the GEM can be varied in different ways:

- Method #1: by changing the charge reaching GEM#2 and GEM#3 by varying the gain of GEM#1
- Method #2: by changing the size of spots reaching GEM#1 by varying the z of the event;



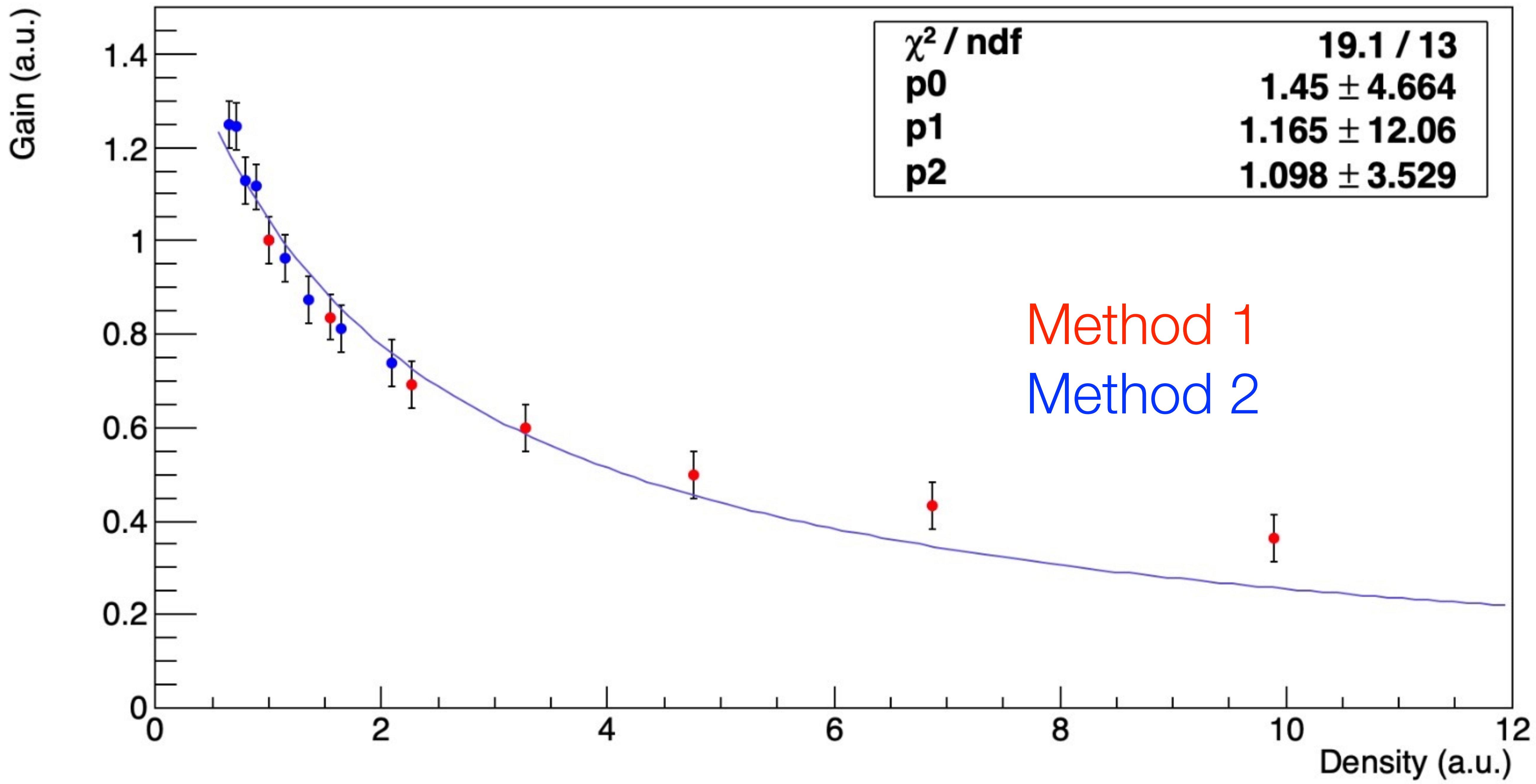
- data recorded with the two methods are well aligned;

A simple model

Electric field in the GEM hole $E_h = \dfrac{Q_h}{\delta C_h}$ is modified by the ion charge Q

(C_h: charge in the hole and δ: GEM thickness)

$$E_h = \frac{1}{\delta C_h}(Q_h - Q) = E_0(1 - \beta n)$$



$$\frac{dn}{ds} = \alpha E_0(1 - \beta n)n$$

↓

$$G = \frac{Ae^{\alpha V_{GEM}}}{1 + \beta n_0(e^{\alpha V_{GEM}} - 1)}$$

$$G = p_0 \frac{p_1}{1 + xp_2(p_1 - 1)}$$

A simple model

$$E_h = \frac{1}{\delta C_h}(Q_h - Q) = E_0(1 - \beta n)$$

$$E_0 = \frac{Q_h}{\delta C_h} \qquad \beta = \frac{1}{n_h} \qquad \rho_h = \frac{10^4\ holes}{cm^2}$$

$$Q_h = (\frac{27 \times 10^{-12} F}{480 cm^2})(\frac{1}{10^4})(480V) = 27 \times 10^{-16} C = 1.7 \times 10^4\ e^-$$

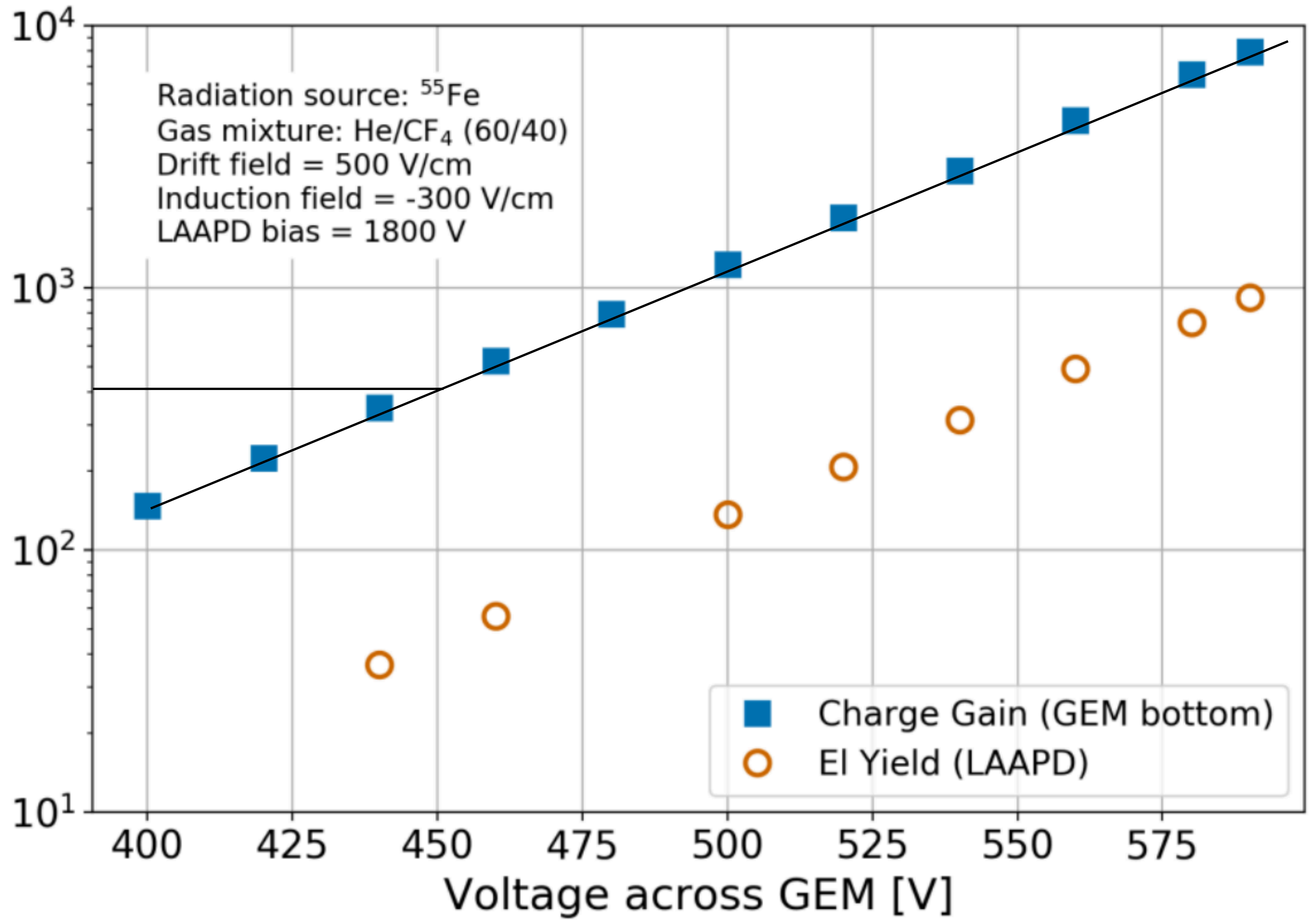
$$\beta = \frac{1}{n_h} = 6 \times 10^{-5}$$

Simulation

- charge clouds have a 3D gaussian shape with some $\sigma_0^T,\ \sigma^T,\ \sigma_0^L,\ \sigma^L$;
- clouds are divided in $160(x) \times 160(y) \times 100(z)\ \mu m^3$ voxels (i.e. pixels and 2 x GEM thickness);
- assume 150 primary electrons and constant (not saturated) gain in GEM#1 and GEM#2;
- the number *n* of electrons in each voxel is multiplied by a gain $G = A\ \dfrac{g}{1 + \frac{n}{n_h}(g-1)}$
    - g is the no-saturated gain;
    - $\dfrac{(g-1)}{n_h}$ is the saturation parameter;
    - A is an overall free parameters (in principle it should be 1);
- Total charge is the sum of all “gained voxels” and total light is obtained by multiplying by 0.07 ph/e$^-$ and camera geometrical efficiency Ω

The gain

$$G(450V) = 400$$

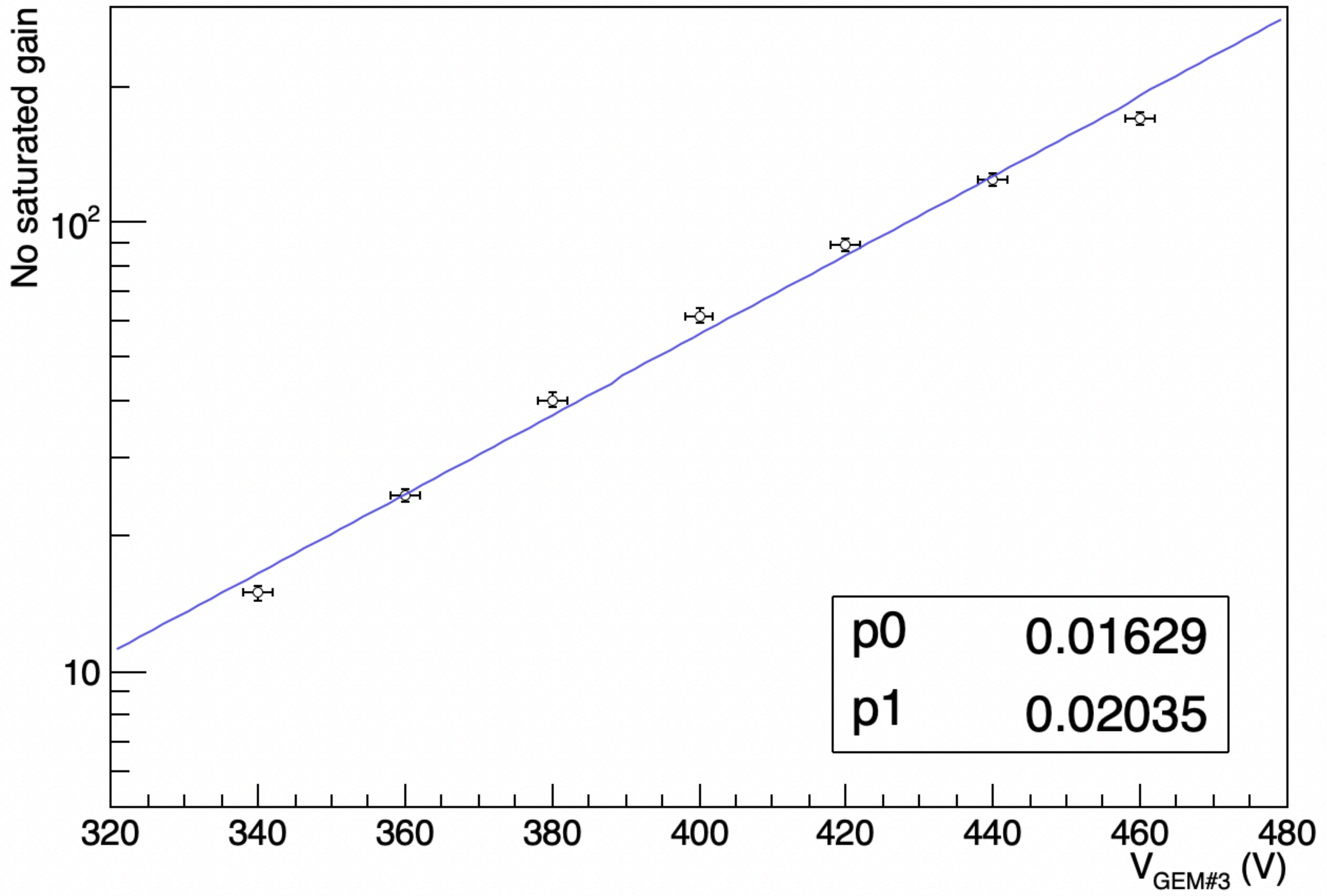


Single GEM gain as measured by Fernando

Single GEM gain as measured by F&K

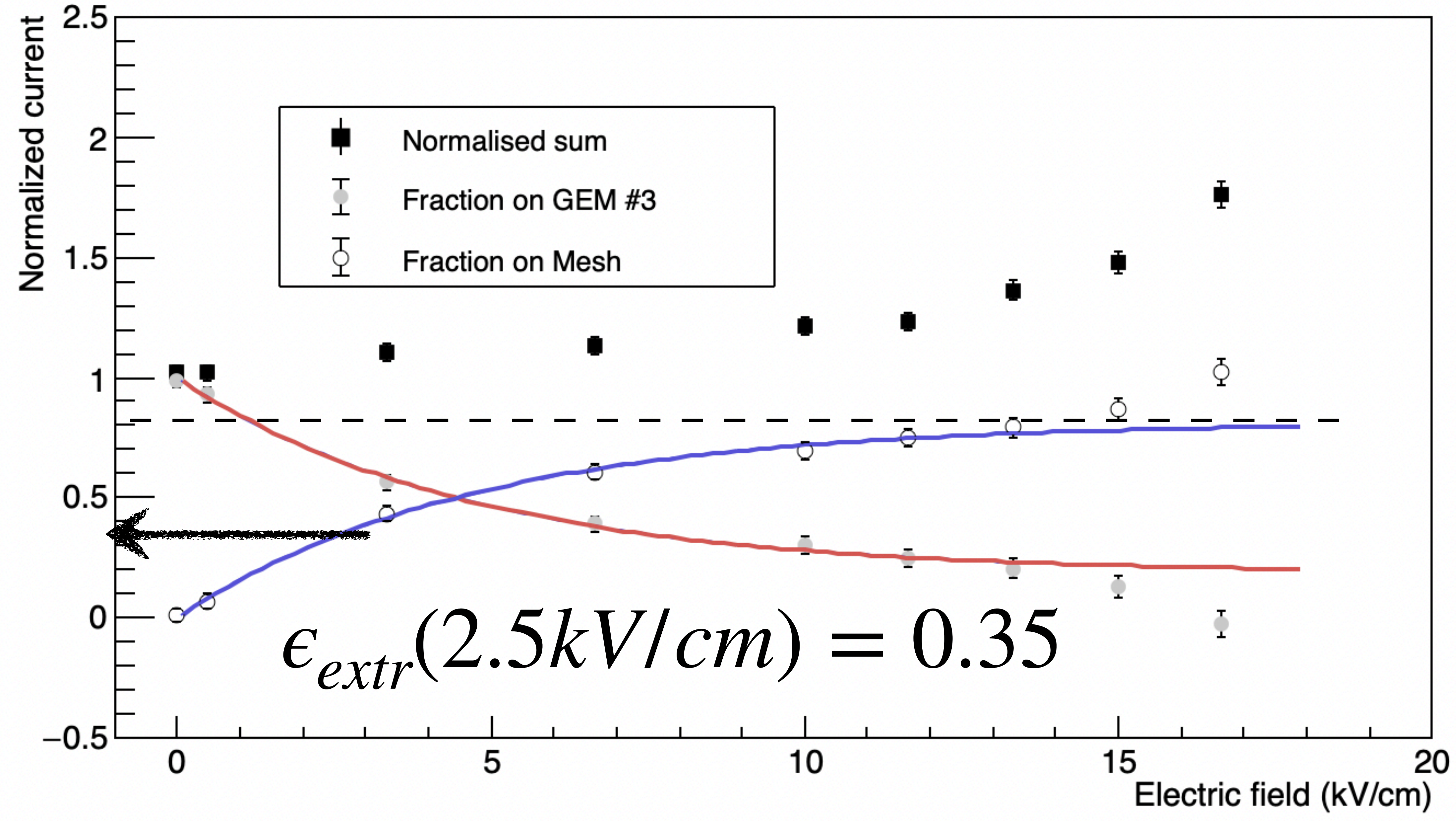
$$\frac{I_3}{I_2}(450V) = G(450V) \times \epsilon_{extr}^{GEM\#2} \times \epsilon_{coll}^{GEM\#3} = 132$$

$$\epsilon_{extr}^{GEM\#2} \times \epsilon_{coll}^{GEM\#3} = 0.33$$



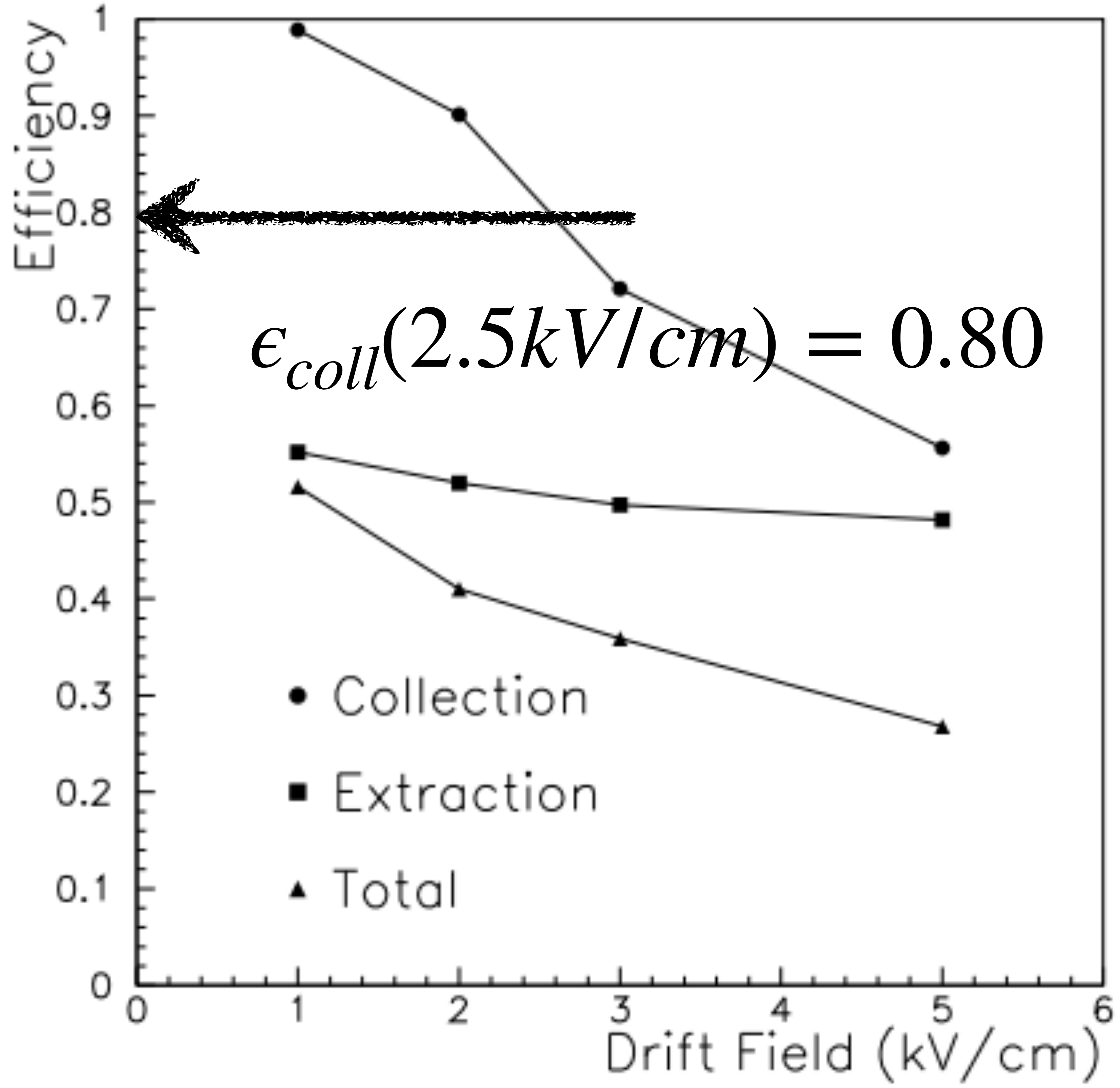
GEM efficiencies

Our measurement



$\epsilon_{extr}(2.5kV/cm) = 0.35$

Simulation (different gas mix)



$\epsilon_{coll}(2.5kV/cm) = 0.80$

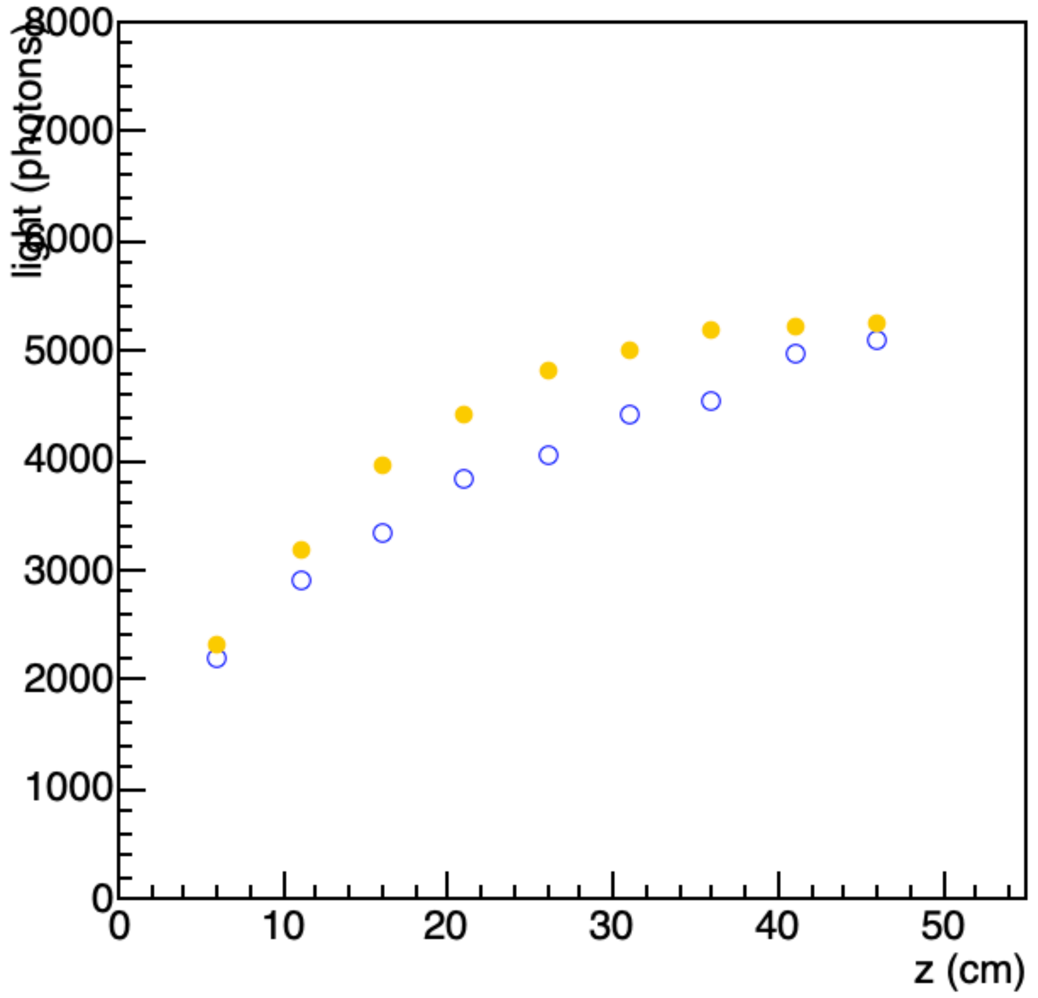
$\epsilon_{extr} \times \epsilon_{coll} = 0.33$ Reasonable

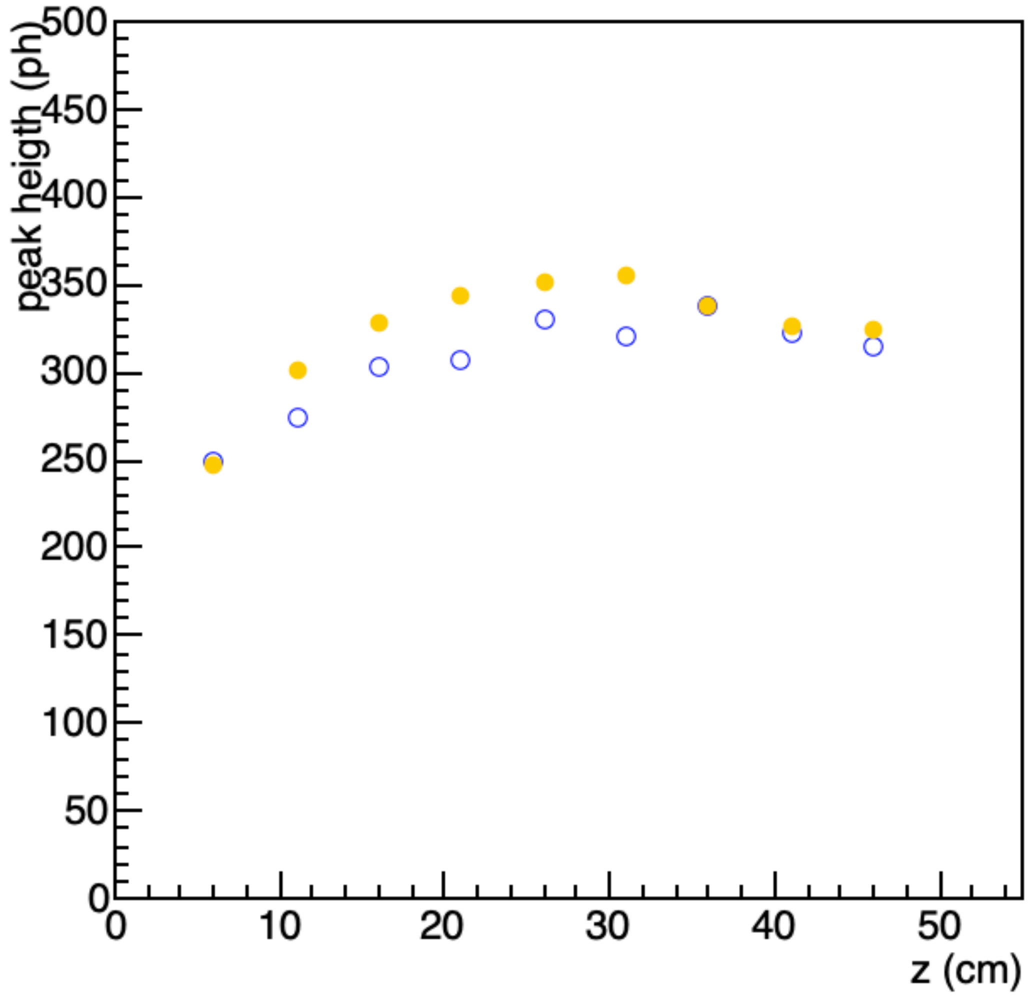
Therefore:

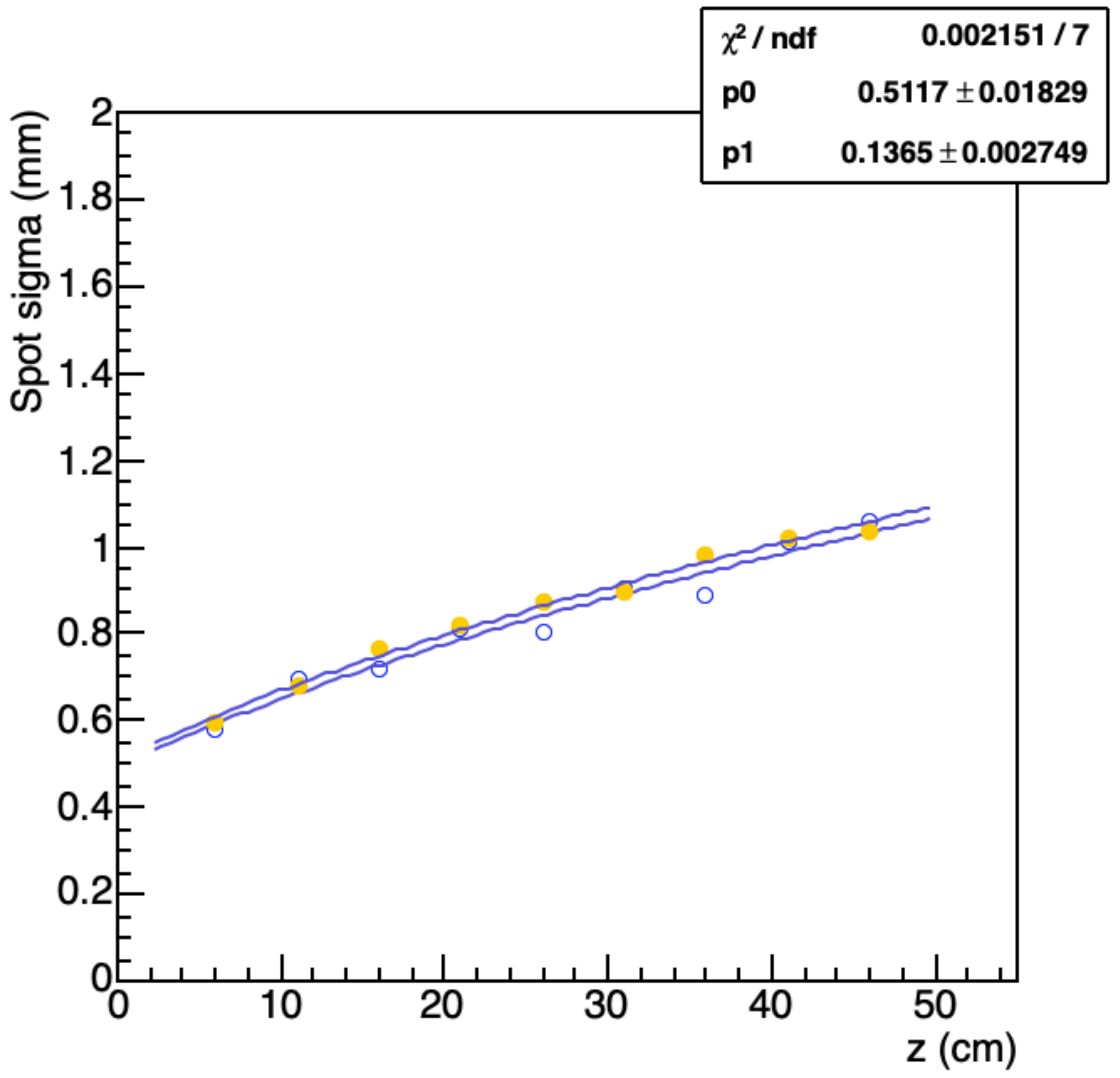
$G_1 = G_2 = 130$;

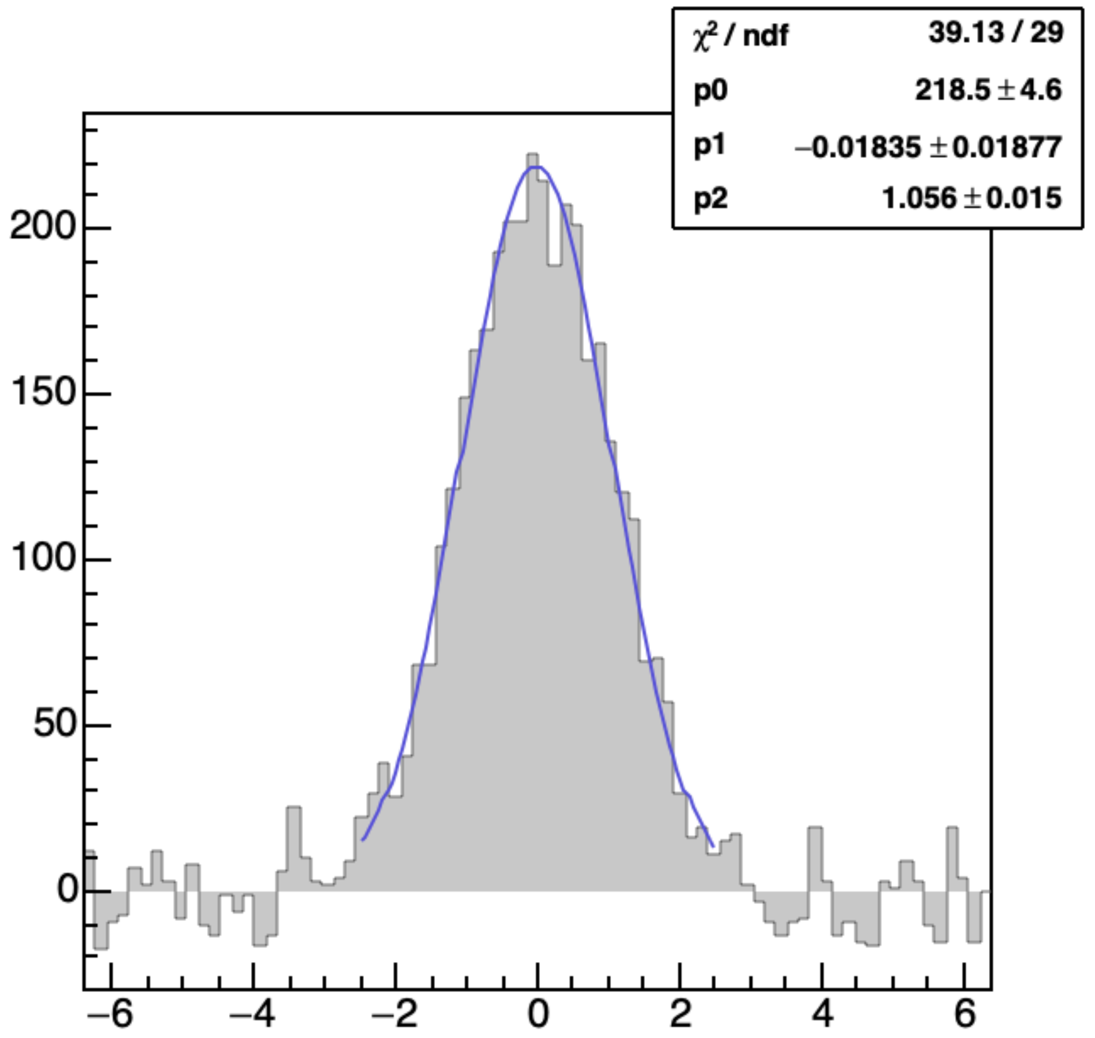
$G_3 = g = 400$;

Simulation/Experimental comparison









$$\beta = 1.0 \times 10^{-5}$$

$$\lambda = 200\ cm$$

$$g = 400$$

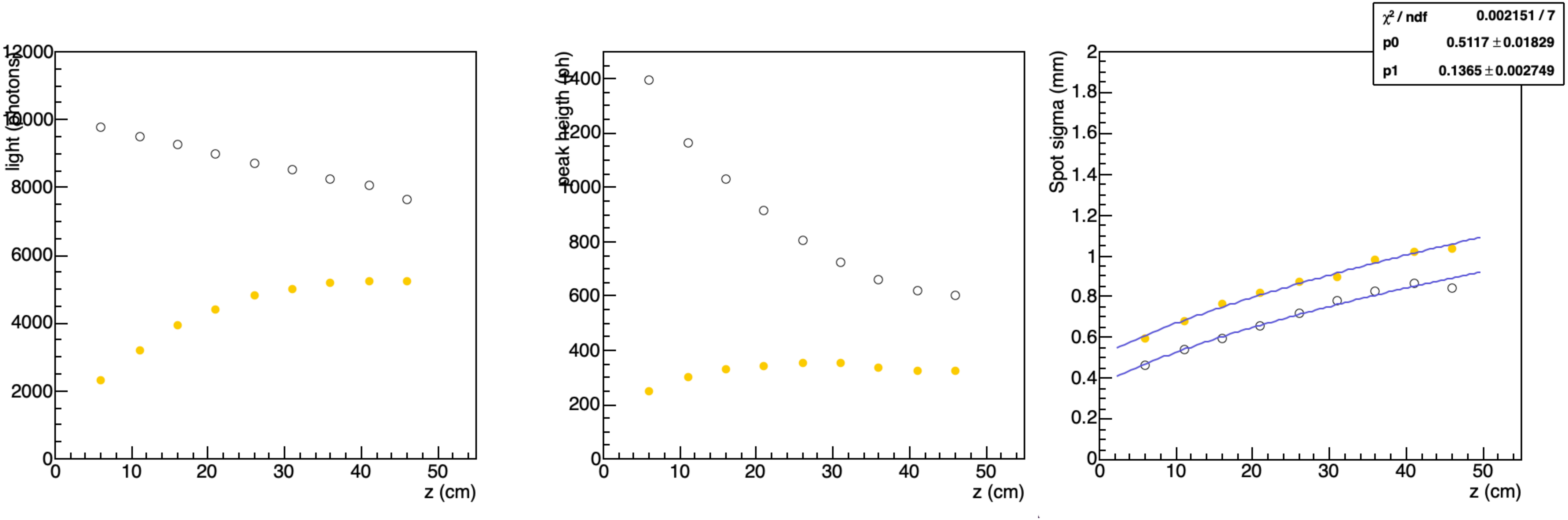
$$A = 2.0$$

$$\sigma_0^T = 350\ \mu m$$

$$\sigma^T = \frac{130\ \mu m}{\sqrt{z(cm)}}$$

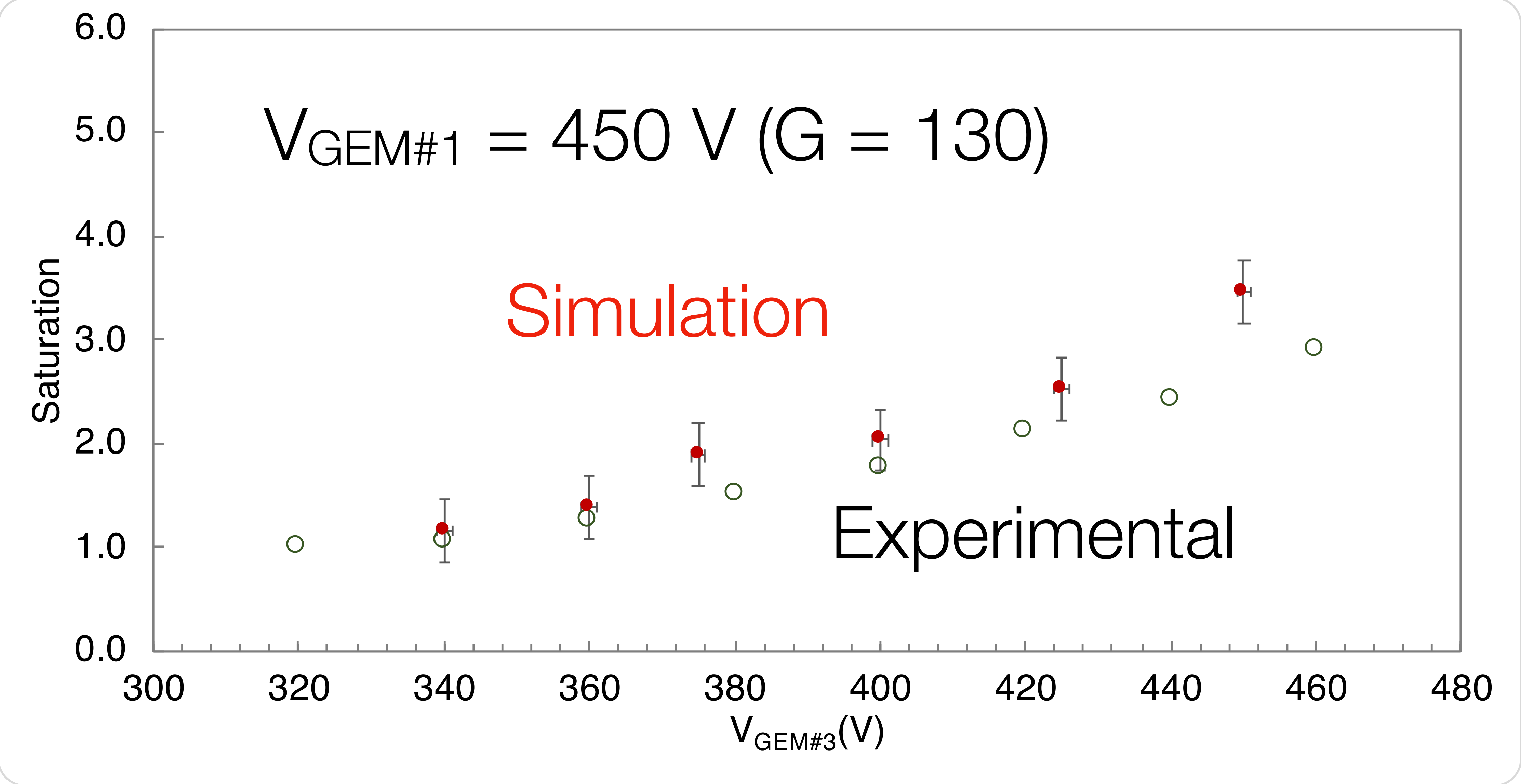
$$n_0 = 150$$

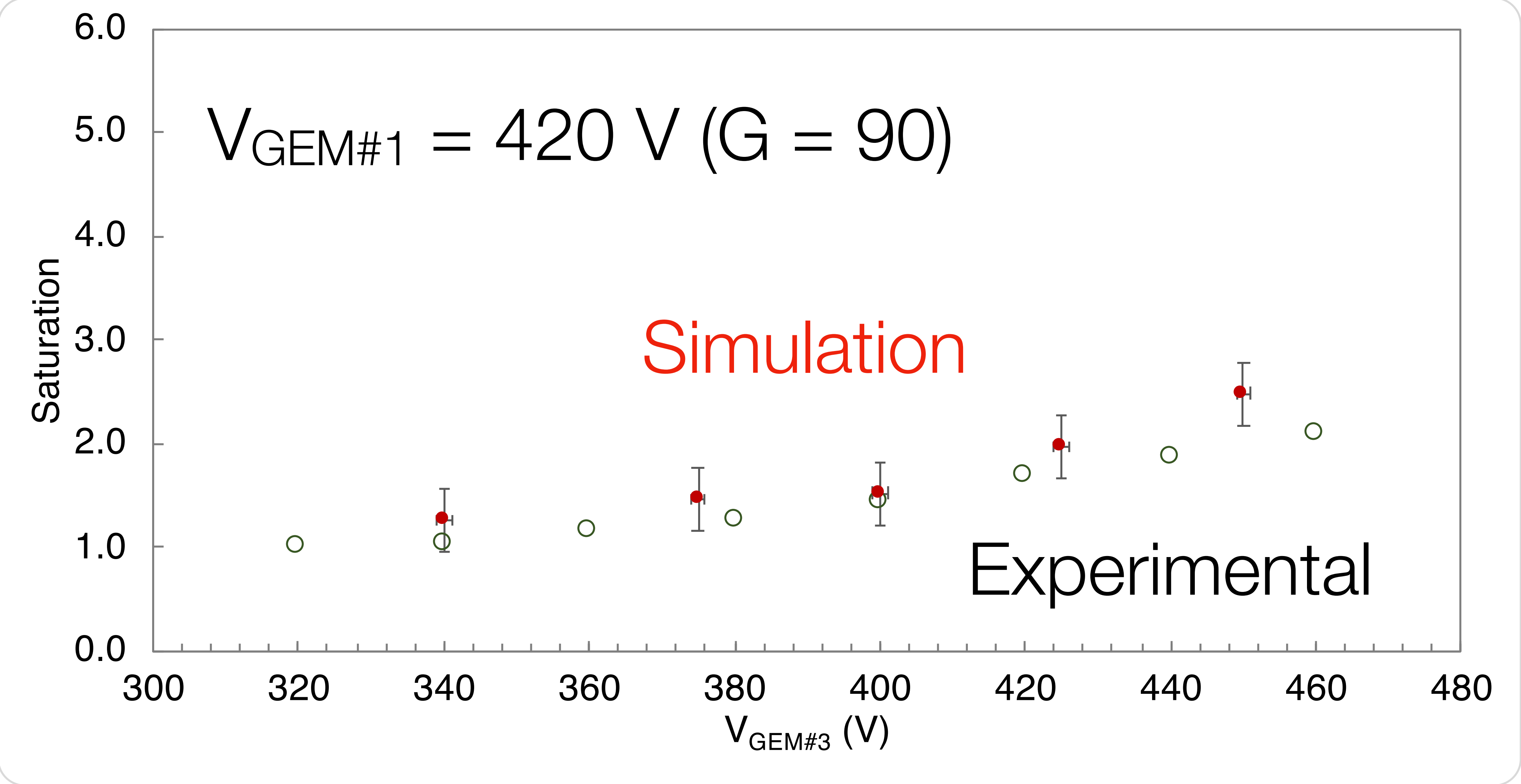
Simulation/Experimental spot shapes (no-saturation)

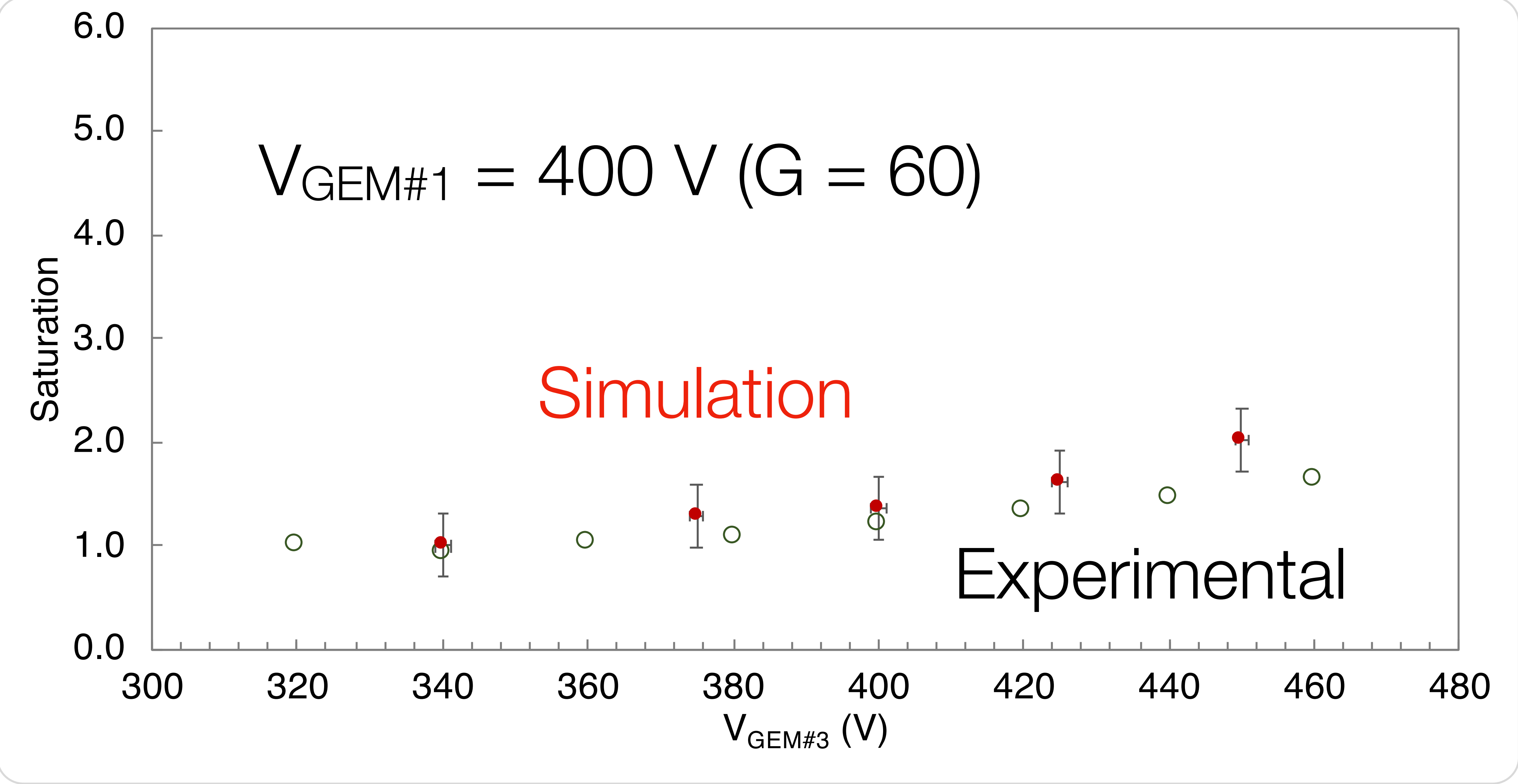


- Saturation effect reduces peak height and total light while increasing spot sigma

Simulation/Experimental comparison (no-saturation/saturation)

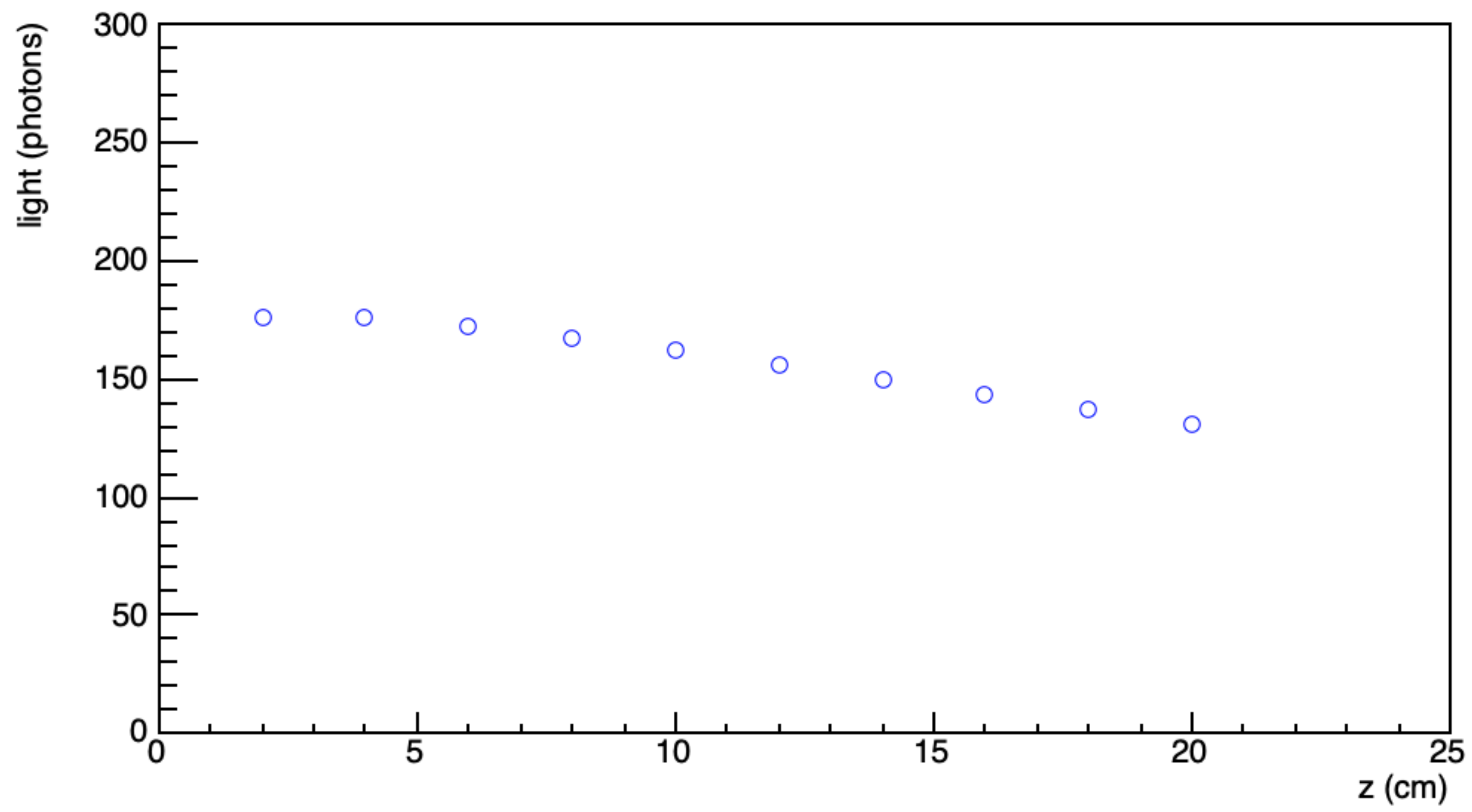


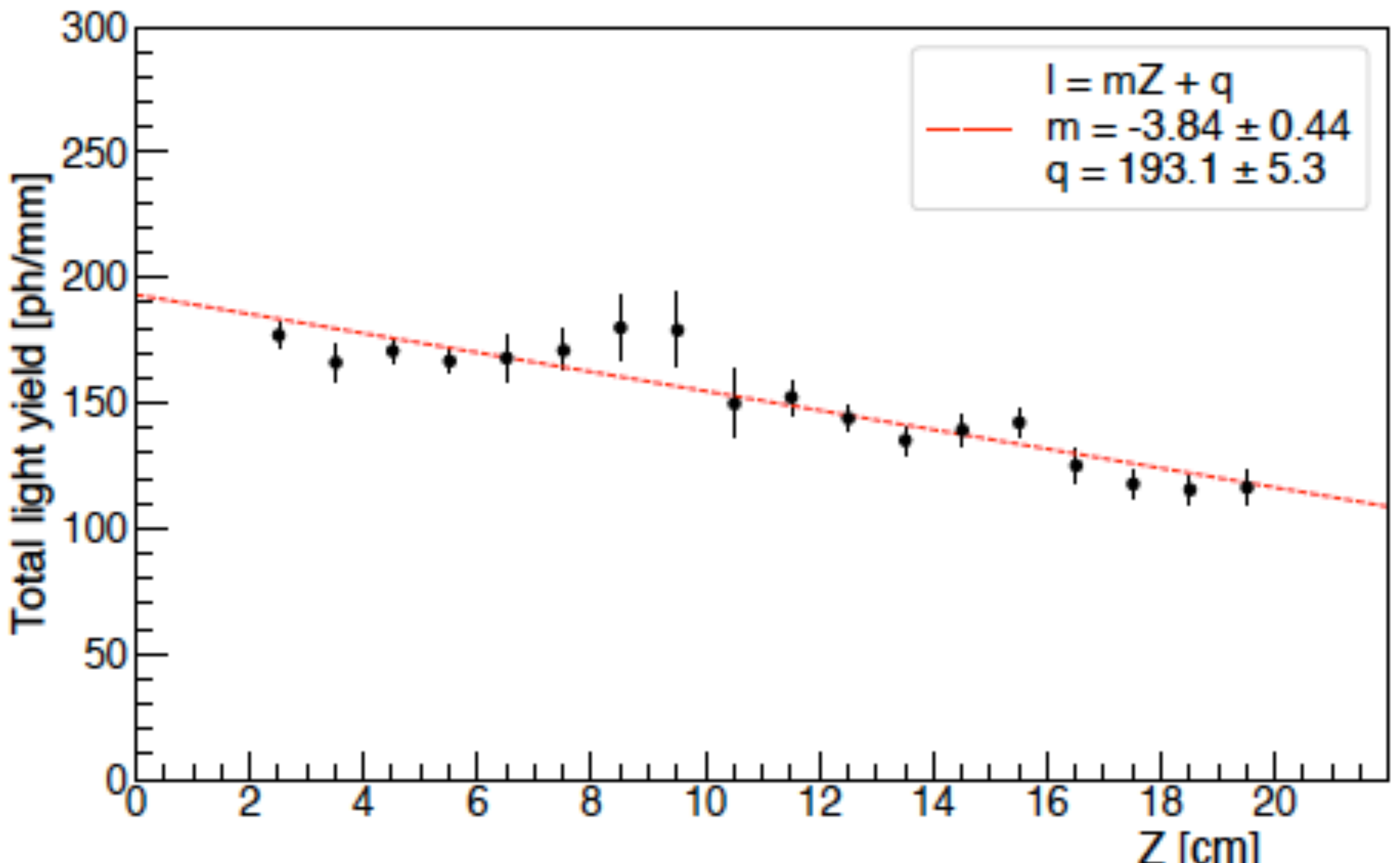




- assuming an average distance of 10 cm in LEMON, measured and evaluated saturation were compared
- A reasonable agreement was found (a little bit over-estimated at high V_{GEM})

BTF Comparison



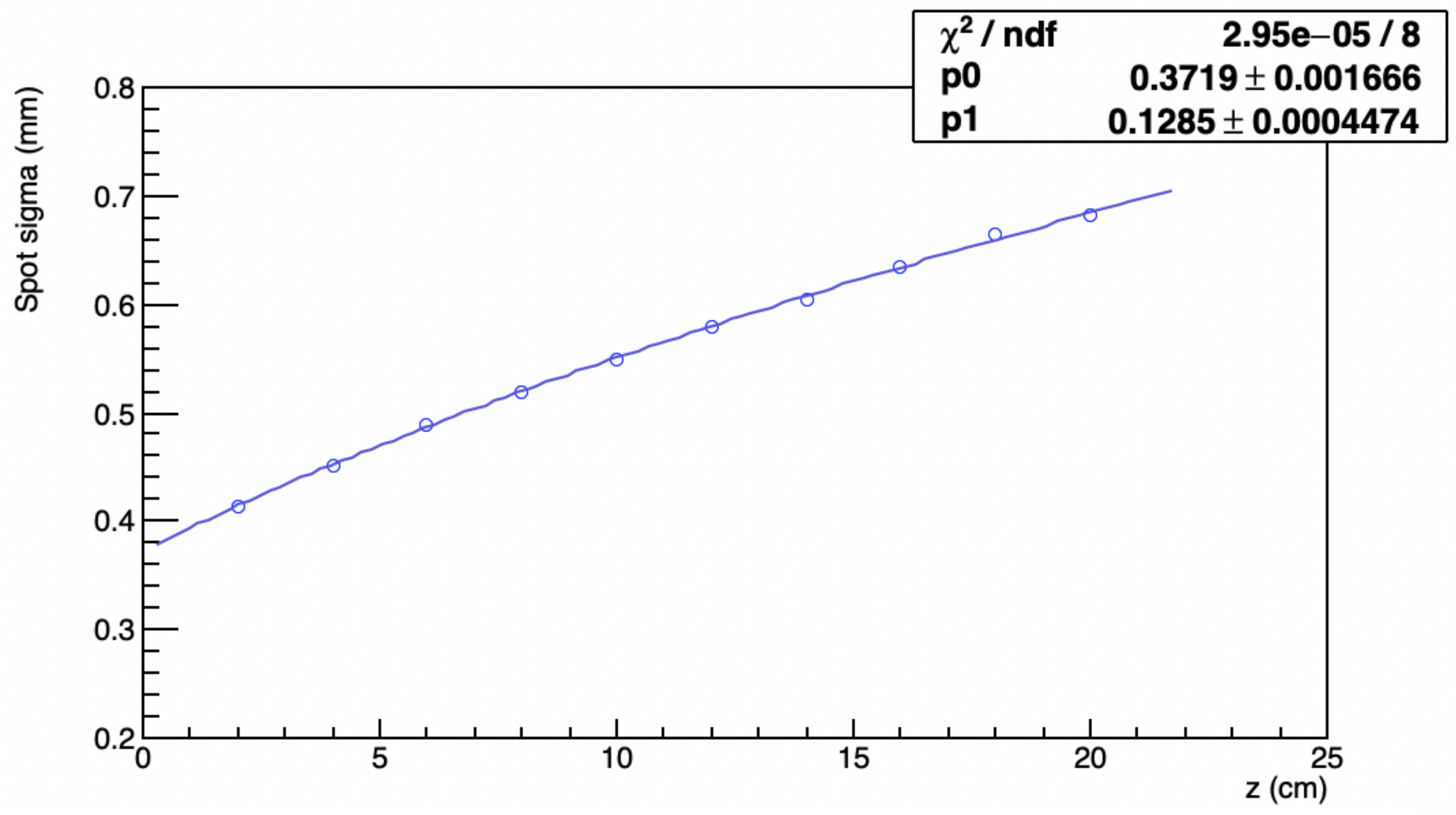


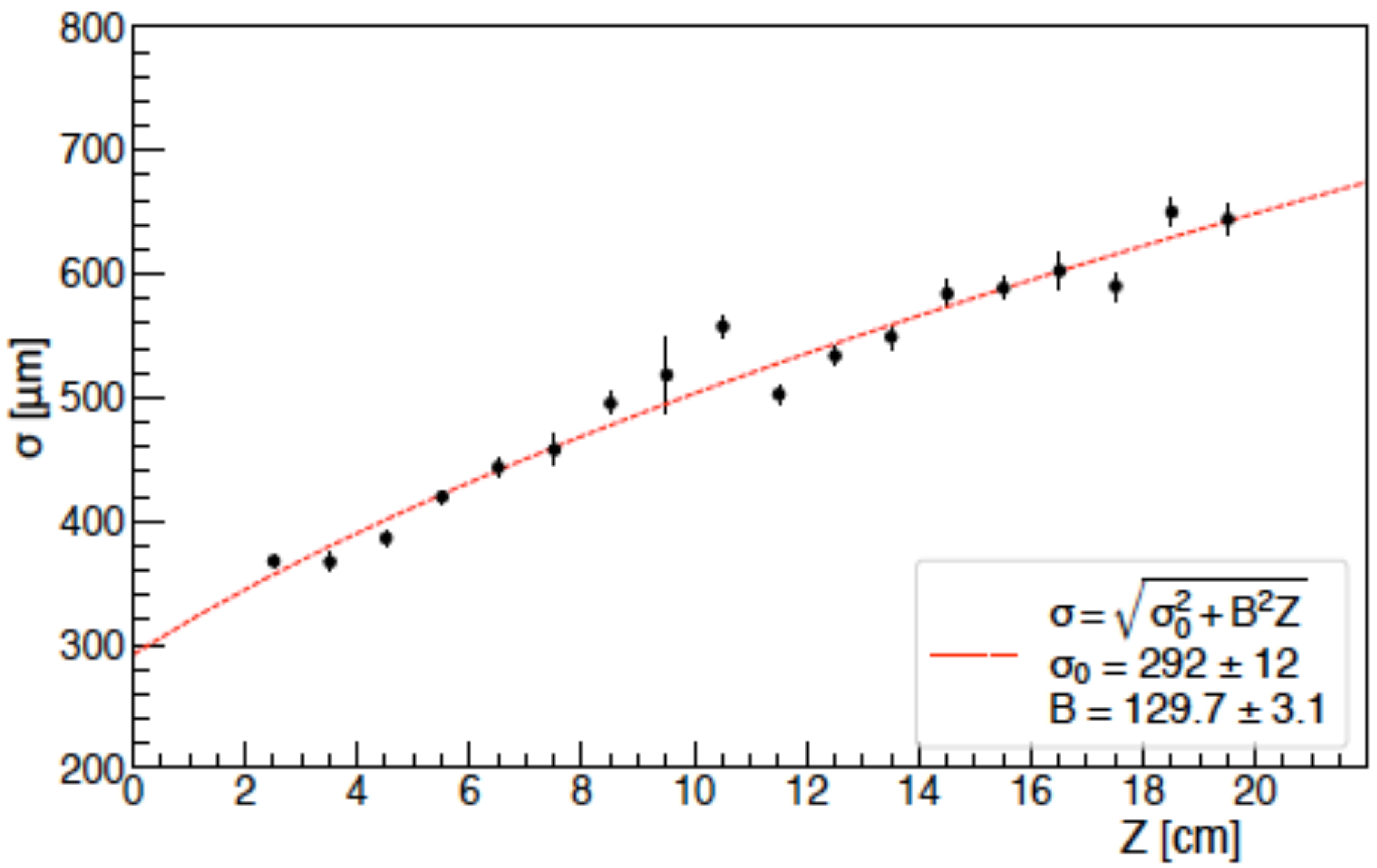
- At BTF we tested LEMON, with mip (5 e-/mm); $n_0 = 5$
- Gain slightly lower than previous measurements because of a lower E_T (65% the no-satured one) $g = 360$
- Poor charge transport efficiency (low field and impurities) $\lambda = 40\ cm$
- Other parameters unchanged w.r.t. LIME

$$\sigma_0^T = 350\ \mu m \qquad \beta = 1.0 \times 10^{-5}$$

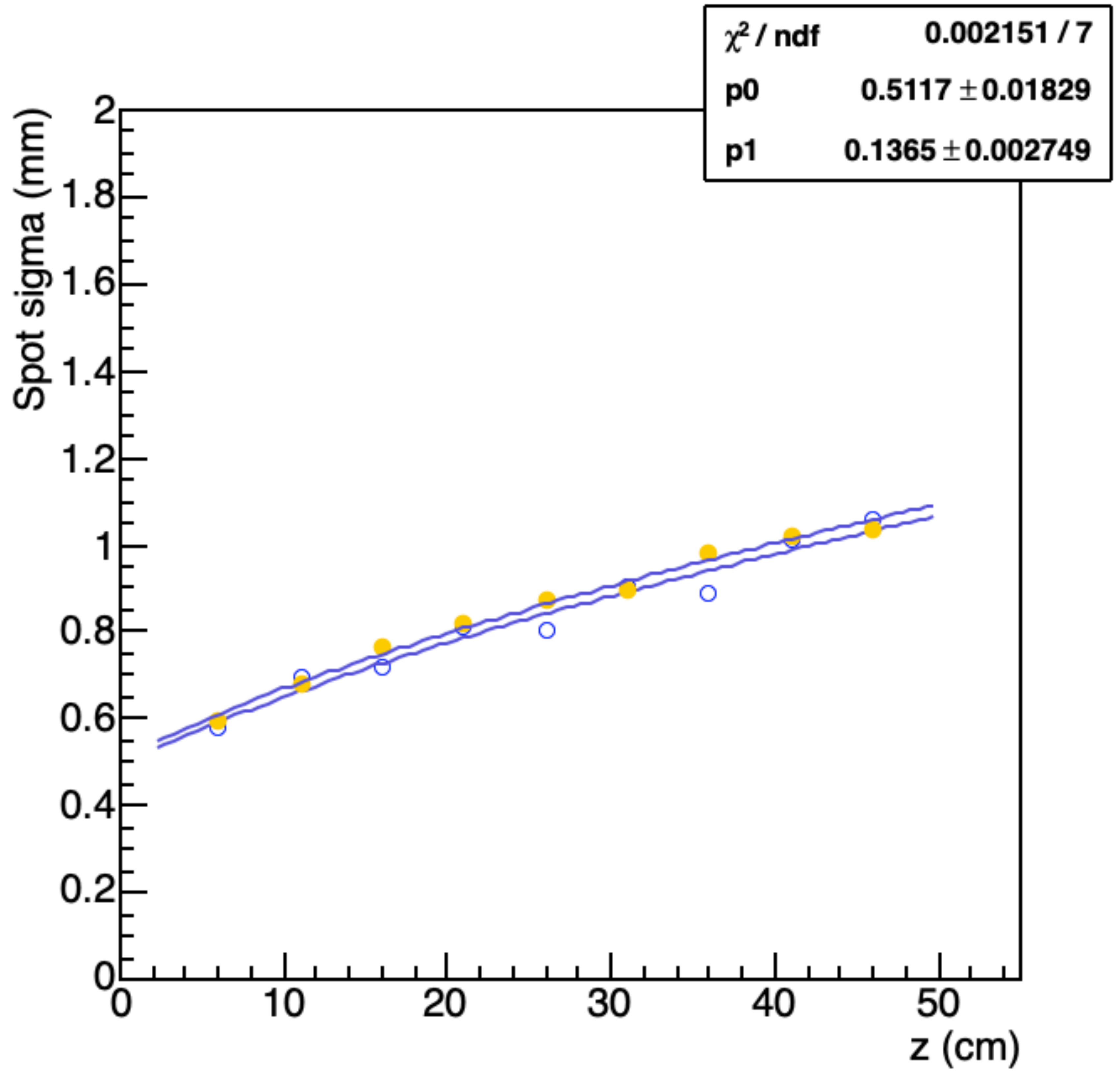
$$\sigma^T = \frac{130\ \mu m}{\sqrt{z(cm)}} \qquad A = 2.0$$

BTF Comparison

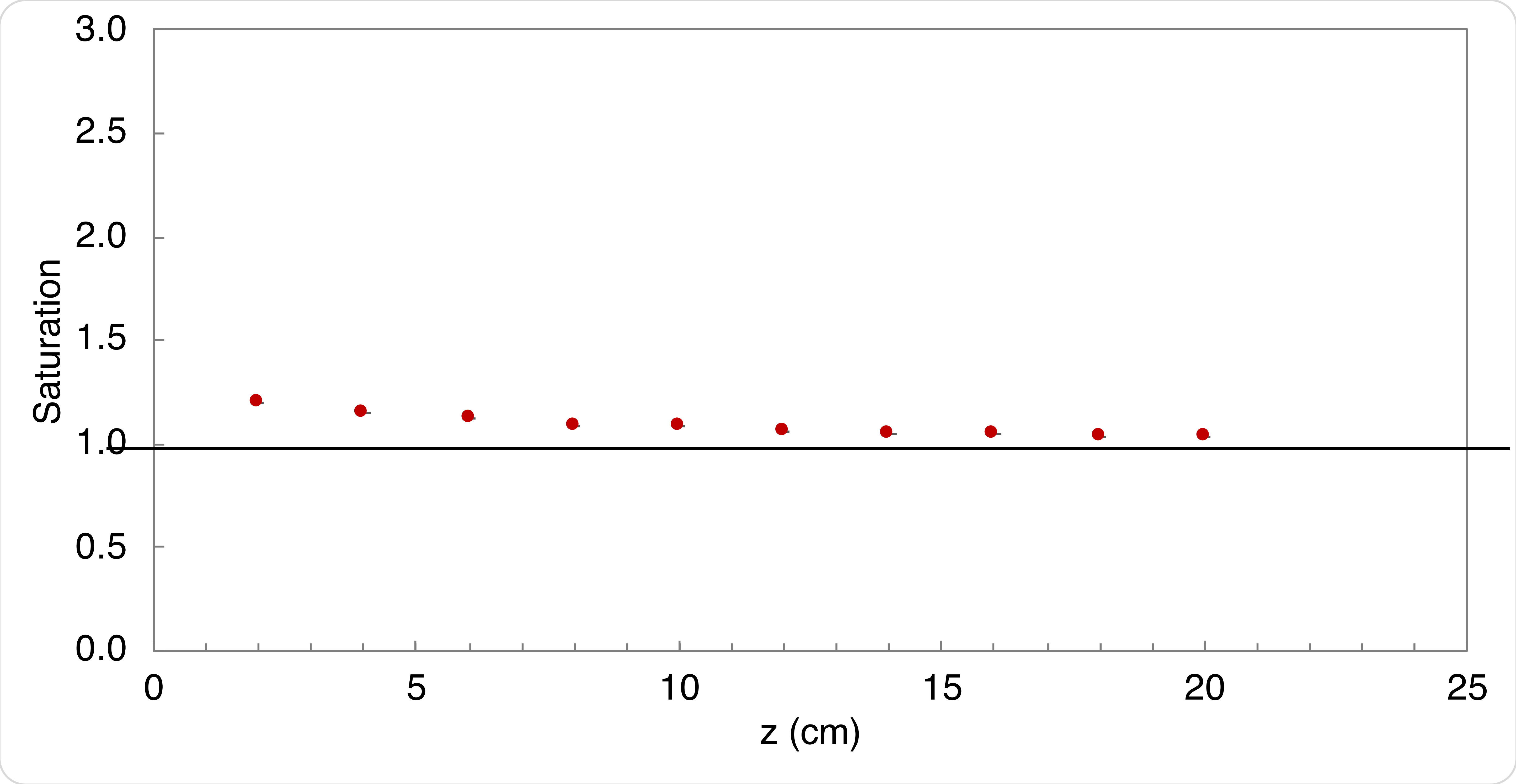




- Starting from same parameters simulation is providing σ_0^T, σ^T values closer to experimental ones and different from LIME

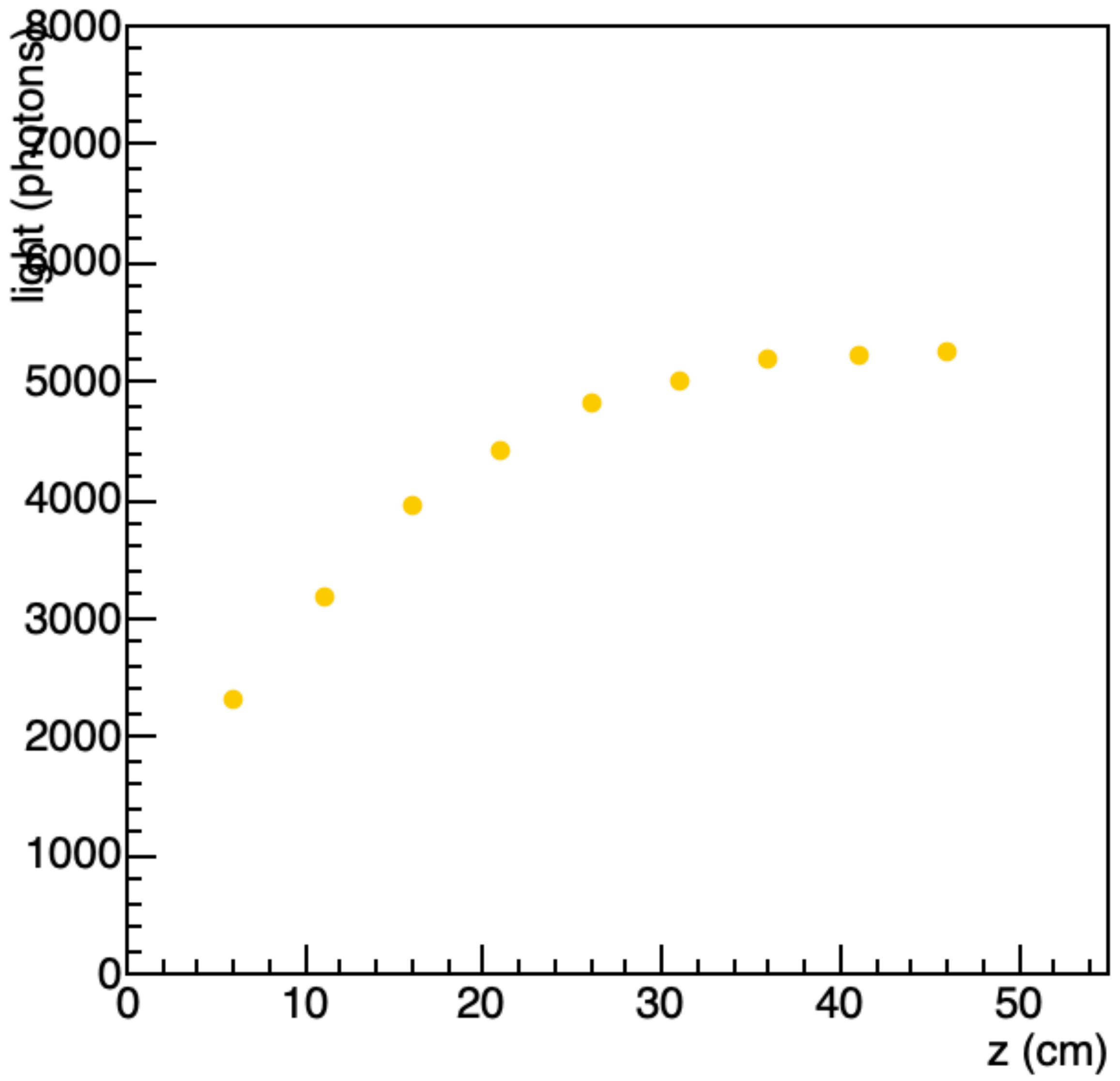


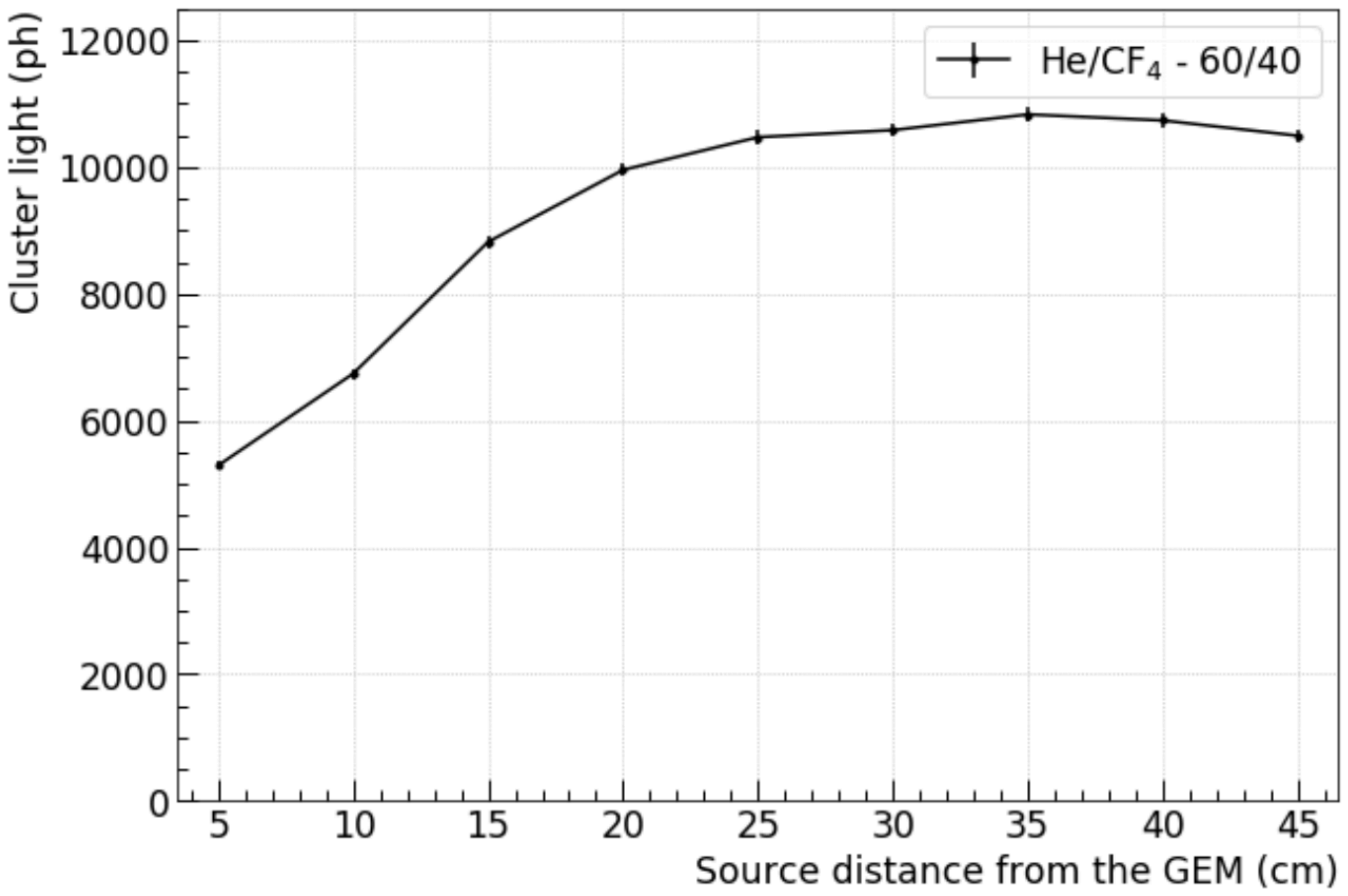
BTF Saturation



- Lemon at BTF seems not to be too saturated

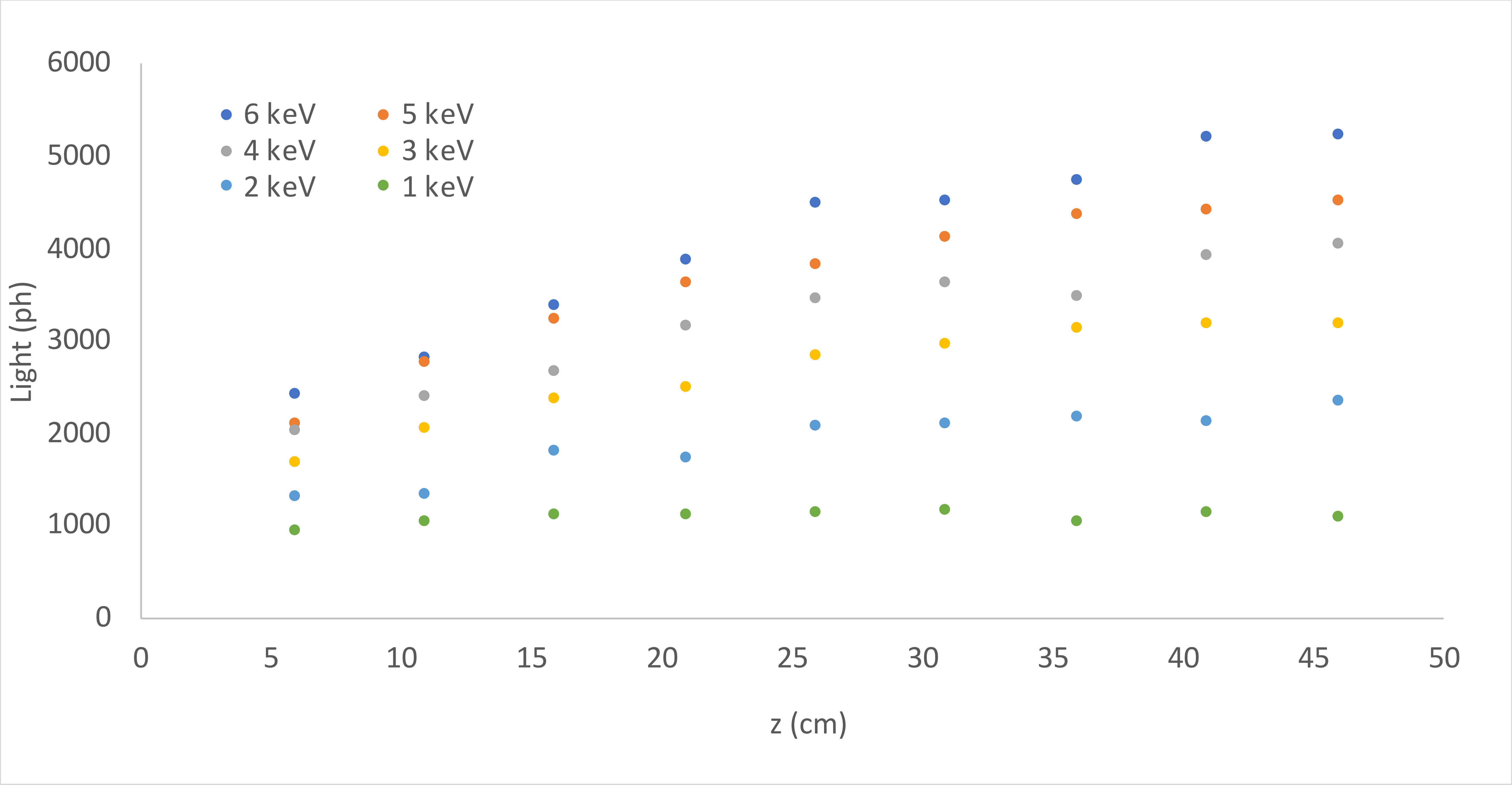
LIME


light (photons)
z (cm)


Cluster light (ph)
Source distance from the GEM (cm)
He/CF$_4$ - 60/40

Exploiting the diffusion

- By means of the simulation, the response to energies in the range 1-6 keV were simulated



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